HYDROGRAPHY OF THE ARID REGIONS.

BY

F. H. NEWELL.

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HYDROGRAPHIC MEASUREMENTS AND IRRIGATION.

The hydrographic investigations of the Geological Survey consist of measurements of the water flowing in the rivers or stored in the lakes of the United States, and, as far as possible, of a study of the laws which govern the distribution and fluctuation of the water supply. The greater part of these investigations are made in the western half of the United States, where flowing water possesses the greatest value and importance. In that part of the country the results of this work, besides being of scientific value, have direct practical application to irrigation and to the problems arising from the deficiency of water for agriculture and other needs of man, for upon the correct solution of these problems is dependent the growth and prosperity of this great division of the United States.

In the eastern portion of the country hydrographic investigations are confined mainly to considerations of the flood discharge of rivers, for here the water supply is usually ample for all needs, and public interest is drawn to such subjects only through an excess of water so great as to be destructive. In the western part of the United States, however, the amount of water at low stages is the object of chief solicitude, and all the fluctuations are watched with care, for agricultural success or failure follows the prevalence of high or low water.

THE ARID REGIONS.

Over a large portion, perhaps one-half, of the continent of North America the rainfall is too small to support those forms of vegetation upon which man depends mainly for his supply of food. This great area, marked by a scanty plant life, lies in a general north and south direction, beginning in high latitudes, where the low temperature forbids the growth of many species of plant life, and continues through the United States and into Mexico till cut off by the belt of tropical rains. The eastern border of this region of droughts is usually taken for convenience as coinciding with the one-hundredth meridian, and from this as the eastern limit it extends to the mountain ranges bordering the Pacific Ocean. This aridity of climate has a fundamental influence

upon the appearance of the country and upon the occupation of its inhabitants. There is perhaps no natural classification under which will fall more groups of facts than that of the division of the United States into these two great regions, the humid and the arid, for in them many of the political and social customs, as well as agriculture, must be radically different.

In this vast area, containing great deposits of mineral wealth, and embracing agricultural land as rich as any on the globe, since the supply of moisture is too small for the needs of man, the examination of all features which modify the water supply and the acquisition of knowledge of its present distribution and character have been recognized as being of great importance, for it is acknowledged that, although the water supply is at best scanty, its future use and efficiency can be greatly increased by a more intelligent utilization of the amount at present available.

There is thus no investigation which bears more fundamentally upon the complete development of the resources of this great region than this careful examination and a recording of facts which are now known, together with a study of the influences which may lead to a more thorough and economical employment of the waters. With our present information a report on these facts can not claim to be complete, but it is rather an introduction to the subject, which, while revealing the deficiency of our knowledge, demonstrates the great necessity of more careful and continued observations in the same line.

The cause of the aridity of this vast area is traceable primarily to the general circulation of the atmosphere and to the shape and relief of the continent. This is perhaps best put by Ferrel in his "Popular Treatise on the Winds," page 183, in which he states:

> If the whole surface of the earth were that of the ocean, or any smooth homogeneous surface, the calm belts, the rain belt, and the dry zones would extend without interruption entirely around the globe with the same regularity which is observed upon the oceans, and everywhere the same climatic conditions would exist on the same parallels of latitude. But on account of the influence of mountain ranges in deflecting the currents of the general circulation of the atmosphere great diversities of climate are found in different places on the same parallels.

It is thus on account of the topographic features of the continent, of the elevation and distribution of the mountain masses, that this arid land stretches in its general longitudinal direction instead of crossing the continent from west to east. Thus a full knowledge of the climate, and especially of the distribution of the rainfall not only in restricted localities but on the continent as a whole, is largely dependent upon a correct understanding and representation of the general topographic features, for it is these which both in a broad and also in a local way are primary factors among causes which make a country inhabitable and prosperous. Therefore, in this discussion of the hydrography of the arid lands, considerable space has been devoted to descriptions of topographic features and local peculiarities, in order that all possible light might be cast upon seeming anomalies.

HYDROGRAPHIC DATA.

Upon navigable rivers in the United States measurements and other examinations have been and are being made under the direction of the Chief of Engineers, U. S. Army, all efforts being directed toward an improvement of navigation, the physical and geological problems receiving less consideration. The character of the work is thus entirely different in scope and results from that undertaken by the Geological Survey; but many of the details, especially of measurements of floods, are of great value in the physical investigations carried on by the latter.

Beyond the field work of these two organizations of the General Government a large amount of hydrographic information has been collected at various times, and many measurements of flowing waters have been made by engineers in the employ of the States, municipalities, or corporations, and this data, much of which is unpublished, would, if all could be brought together, prove of great value. For example, the state engineering department of California has published data concerning the principal rivers of that state; the State engineers of Colorado have done a similar work on a smaller scale; the northern transcontinental survey also acquired many facts in Montana, Idaho, and adjoining States, and various exploring parties in all parts of the West have occasionally gauged streams and estimated discharges. The results of many of these measurements will be discussed later, in connection with descriptions of the various drainage basins.

The data collected from the sources just mentioned have been reduced to common units and arranged in form convenient for making comparisons, and as many results as can be obtained at this time have been thus brought together and republished in condensed form, with brief explanatory remarks. On the index map, Pl. LVIII, is shown the location of the principal drainage basins and the points at which the gaugings referred to in subsequent discussions were made.

During the year ending June 30, 1891, the Geological Survey received reports of the daily gauge height of many rivers of the West at points where gauging stations were previously established and discharge measurements made, and by this means the daily mean discharge at these several localities has been computed. These discharges afford a comparison with those obtained in previous years, and add greatly to the knowledge of the régime of these rivers. On subsequent pages the results of these computations, are given and on the accompanying plates the daily discharges for various stations are shown in graphic form. In connection with these, the data obtained from other sources have been introduced in geographical order.

DEFICIENCY OF WATER.

As to the practical bearings of these investigations it is sufficient to state that the area cultivated by irrigation in most drainage basins of the arid region is far larger than can be covered by the present water

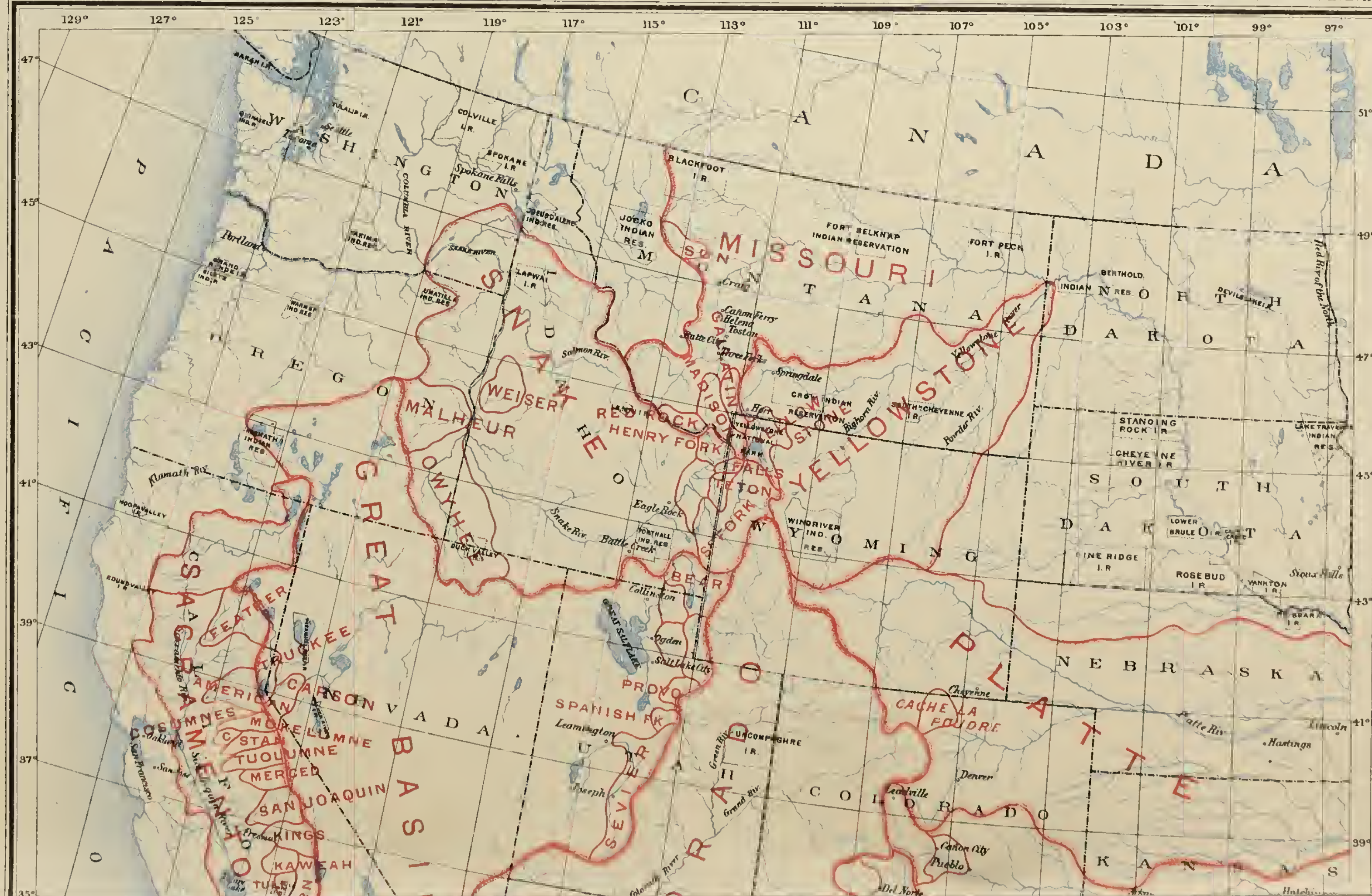
supply, and each year the crops upon thousands of acres in various localities are injured or lost for lack of water at critical times. Besides this, there is a still greater acreage which can be reached by canal systems constructed or projected, including bodies of land as good as that now under cultivation and sometimes better, and in addition to these irrigated and irrigable lands there are in many parts of the arid region plains of arable land so vast that by no possibility can they ever be brought under irrigation. Thus as a whole the water supply can never be conserved too carefully, for there will always be fertile lands in excess of that supply.

With greater economy in the use of the present available water, a greater acreage each year can be successfully cultivated, but there will soon be a limit to the slow growth in this manner, for under ordinary circumstances it will happen that each year the amount of land successfully cultivated must fluctuate with the variations of water in the rivers; in years of large flow, the farmers will be prosperous, while, when droughts occur, a certain portion of the crops will be lost, if dependence is placed wholly upon the unregulated flow of the streams.

There are, however, as above mentioned, floods at irregular intervals bringing with them great quantities of water. It has occurred to thousands of individuals, on seeing on the one hand rich soil lying barren for lack of moisture and on the other destructive torrents, that by the proper conservation of these floods, by saving the waste waters in times of need, not only will the farmer be able to raise all his crops, but, in addition, great tracts of land now unproductive may be made sources of wealth to the community. It is only a question of time, it may be five years or fifty, when dams will be built to hold back this flood water, but the building of these will proceed slowly, for the conditions of success in such enterprises are entirely different from those pertaining to other irrigation projects.

There can be nothing of an experimental, temporary nature in designing storage works as there is in the case of diversion dams in rivers or of canal works. They can not be essentially changed or modified, and the washing away of one is not a matter of loss to the owners alone, as with canal headworks, but may involve the destruction of lives and property in distant localities. There are in the history of the last few years too many examples of this to call for further comment, and it is now generally recognized that not only must large sums of money be expended to construct these storage dams securely and permanently, but that a rigid inspection must be made by competent authorities.

Before any steps can be made toward the construction of such dams their builders must have ample and accurate information on which to base conclusive estimates as to the success of the enterprise. They must know, among other things, not only that the reservoir thus created will be of ample size, but that it has a reliable and sufficient water supply and that it will not be exposed to floods which can in any combination of circumstances tear it down.


CANADA
WASHINGTON
OREGON
IDAHO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
NEBRASKA
COLORADO
KANSAS
UTAH
NEVADA
PACIFIC OCEAN
MISSOURI
YELLOWSTONE
PLATTE
SNAKE
GREAT BASIN
COLORADO
SACRAMENTO
SAN JOAQUIN
WEISER
MALHEUR
OWYHEE
RED ROCK
HENRY FORK
MADISON
GALLATIN
BEAR
PROVO
SPANISH FK
SEVIER
CACHE LA POUDRE
FEATHER
TRUCKEE
AMERICAN
CARSON
COSUMNES
MOKELUMNE
STANISLAUS
TUOLUMNE
MERCED
KINGS
KAWEAH
FORT BELKNAP INDIAN RESERVATION
FORT PECK I.R.
BLACKFOOT I.R.
JOCKO INDIAN RES.
COLVILLE I.R.
SPOKANE I.R.
STANDING ROCK I.R.
ROSEBUD I.R.
PINE RIDGE I.R.
Portland
Spokane Falls
Salt Lake City
Ogden
Denver
Cheyenne
Pueblo
Leadville
Helena
San Francisco
Snake Riv.
Klamath Riv.
COLUMBIA RIVER
Red Riv. of the North
129°
127°
125°
123°
121°
119°
117°
115°
113°
111°
109°
107°
105°
103°
101°
99°
97°
47°
45°
43°
41°
39°
37°
35°
51°
49°

INDEX MAP OF RIVER MEASUREMENTS.

Showing the relative location of the drainage basins and the principal places at which gauge readings have been made.

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Scale.

100 0 100 200 300 400 500 600 Miles

In most of the drainage basins where the typography is such that the floods are sudden and of short duration, the actual amount of water discharged by rivers is in general greatly overestimated, and before any notable reservoir can be made the question arises as to whether there is enough water to fill it. Our information on this point, though it is one which deeply concerns these basins, is unfortunately meager. The importance of the case, however, justifies a careful examination of the known facts and their publication. It is hoped that a discussion of these data may serve, perhaps, as a foundation for a protracted examination in the future, when there is a more general appreciation of the fact that the permanent agricultural growth of this land must await the completion of a long series of such careful observations.

INCREASE OF WATER DUTY.

Every improvement which tends to greater economy in the use of the present water supply adds ultimately to the acreage which can be cultivated. Water is wastefully used in many instances, there being a lack of economy in the methods of conducting it to the fields and in applying it to the soil. There are no inducements toward economy and no unity of action by which economy can be enforced. Each canal company or association of canal-owners is content if sufficient water can be procured to cover its own claim, regardless of the possible rights of others. In a case where a company sells water there is rarely any attempt to enforce economy, or inducement held out to users of the water to save it or make it cover the greatest possible extent of land.

The common method of irrigating, especially when used on alfalfa and other forage crops and the small grains, is that of flooding, the water being caused to spread over the ground to an average depth of 2 to 3 inches or more. For other crops it is allowed to run along the furrows until the ground between each two furrows is saturated. For fruit trees or vineyards small trenches are plowed or dug leading from the lateral or small distributing ditch to each tree, the water being allowed to settle around the roots of the tree or vine.

Experience, however, is gradually teaching the farmer that better success can often be obtained with small amounts of water intelligently applied than with greater, and also that as irrigation extends less and less water is required on many soils, this being due perhaps to a general raising of the moisture in the ground or to a clogging of many points of escape. The result is that less water per acre is used and needed on the older lands than on the newer.

The area of land which can be irrigated by a given quantity of water is known for convenience as "the duty of the water." The unit in general use is the second-foot, or cubic foot per second, that is, a quantity of water equaling a stream 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot every second. From what has been said, it is obvious that the duty of water varies much, being greater on

old land than on new, and differing with the soils, as well as the skill and customs of the irrigators.

There are unfortunately no reliable or detailed measurements to show what the actual water duty is. A number of estimates have been made, none of which agree very closely. Powell[1] in his first book on the arid lands gave the average water duty in Utah, under good conditions, as reaching 100 acres to the second-foot. The average of a number of estimates of the amount actually used in Utah, under ordinary conditions and with little skill, was a trifle over two-thirds of this, or about 70 acres. In Wyoming and Idaho, where water was plentiful, land new, and irrigators unskilled, the duty was from 30 to 40 acres only. In Arizona and California calculations have been made that with care a second-foot can be made to cover 120 acres, or even more.

Another way of expressing the duty of water is in acre-feet—the quantity of water covering an acre 1 foot in depth—1 acre-foot thus being equivalent to 43,560 cubic feet. Thus a water duty of 1½ acre-feet to the acre means that during the course of the irrigating season a quantity of water has been applied equal to a depth of 1½ feet over the ground. Some such arbitrarily selected duty of water is taken in all discussions as to the utility of water-storage systems, in order to compute the relation between their capacity and efficiency.

It is evident that the duty of water will depend considerably upon the point at which water is measured. If, for example, water is measured when entering the field where used, a higher duty will result than is found when the water is measured at the head of the canal, for in the latter case a certain quantity is lost by seepage and evaporation before it can reach the land on which it is to be employed. Further, a still less duty is shown if the water is measured in the river before entering the canals, unless, as is frequently the case, a certain amount returns to the river by seepage, to be used over again by land below.

WATER STORAGE.

Water storage for purposes of agriculture is comparatively new to the Arid Regions of the West, and is practiced to a small extent relatively to the whole area needing it. In order then to obtain certain definite ideas concerning relative costs and values, it would be useful to compare this with water storage as practiced in many parts of the country for municipal supply. The greater number of cities of the United States own or control reservoirs for holding the water, either for purposes of clearing it or as a safeguard against accident.

One of the most important conceptions in connection with a comparison between municipal supply and that for agricultural purposes is the vastly greater quantities needed and the less value of water for the latter use. The amount which is used in irrigation is so much greater than

[1] Reports on the lands of the Arid Region of the United States, J. W. Powell, 2d ed., 1879, p. 84.

that needed by a city that it is difficult at first to comprehend the difference, and many persons have been disappointed in their attempts at storage by failing to take into account in their original estimates the losses and waste which necessarily take place in connection with the free use of the water for agriculture.

If it is assumed that 100 gallons per day is ample for each inhabitant of a small city, and, on the other hand, 1 acre foot is sufficient to irrigate 1 acre, a comparison can be made between the relative values of these two water supplies. One acre-foot equals 43,560 cubic feet, or about 326,000 gallons. Neglecting in both cases losses from evaporation, this 326,000 gallons on the above basis would supply 9 persons with water for a year. In other words, 1 acre-foot of stored water would either irrigate 1 acre, or, if carried to a city, would supply 9 persons, and 1,000 acre-feet would water 1,000 acres or supply a city of 9,000 inhabitants; but now if we compare the relative value of the property concerned the difference is at once apparent. The value of the irrigated land, at a liberal estimate, can not ordinarily be placed over $50 per acre, while the valuation of city property, taking the average for the United States for this number of inhabitants, would be about $5,000,000; that is to say, the property which must bear the expense of storing water is in the case of agriculture $50,000, and in the case of the city, needing the same amount, one hundred times as great, or $5,000,000. Taking these facts alone into consideration, it would seem that the city can afford to pay a vastly greater sum for storage, and can make use of opportunities for storage which are far too expensive for rural districts.

There are many minor considerations which modify the above comparison, but it is sufficient to demonstrate the general fact that for agricultural success water storage must be very cheap and of enormous capacity. The farmer can not afford to take the same chances of success or to repair injuries to the same extent that a city can, so that far greater caution, engineering skill, and foresight must be employed than in the case of our ordinary municipal supplies.

In preliminary discussions of water storage for purposes of irrigation one of the most important facts to be borne in mind is that success does not depend directly upon the quantity, distribution, or fluctuations of the rainfall. A full and exact knowledge of this subject is of course important and valuable as affording collateral data, but since the amount of water flowing in the stream is remotely affected by variations in rainfall, these data can not be depended upon primarily. Comparing the rainfall and the snowfall, it may be said that precipitation in the form of snow is of greater importance than the rain to irrigation schemes, for the useful floods of most rivers are due rather to melting snow than to rainstorms. The time of the year at which snow falls, whether early or late in winter, and the temperature of early spring, have great influence upon the quantity and intensity of floods. This is seen on the various plates of discharge referred to in the following pages. By comparing

one with another it will be noted that melting snow furnishes the water necessary for great spring floods, this quantity being increased or diminished day by day as the temperature rises or falls, so much so that in cases where the river gauging station is near the headwaters of a stream the diagram of river discharges to a certain extent would serve as the diagram of fluctuations of temperature.

Pl. LIX has been prepared to show, in condensed and generalized form, the lack of coincidence between the average discharge and the mean annual rainfall for each month of the year in four widely separated basins. In each of the four diagrams on this plate the dotted line represents the mean annual rainfall, and the solid line the average height or discharge of the river. The months of the year are shown by vertical spaces, and horizontal lines give the height of water or quantity of discharge and also the depth of rain.

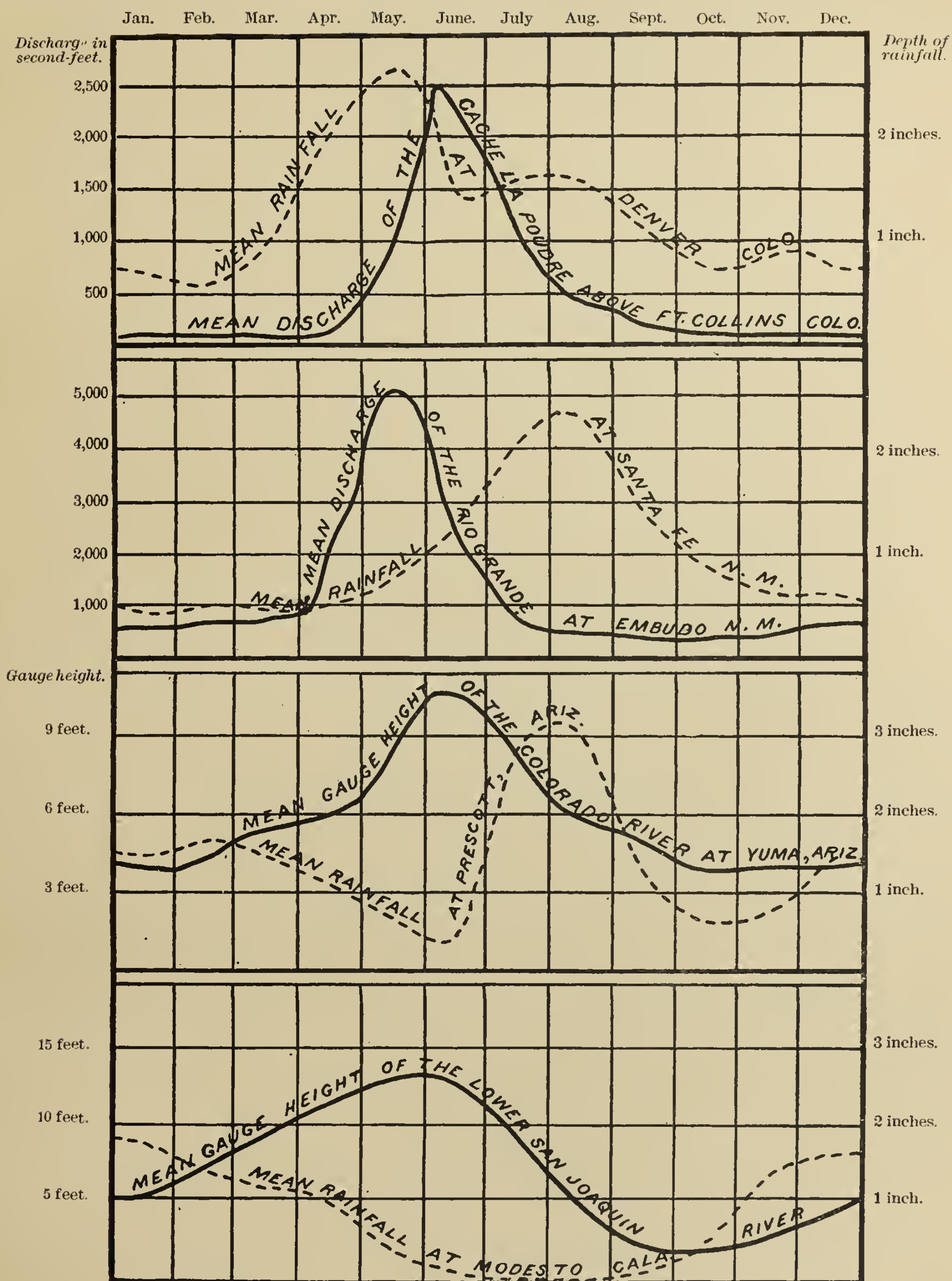
In the upper diagram the mean discharge of the Cache la Poudre, above Fort Collins, for all years during which measurements have been made, is compared with the mean rainfall at Denver, Colorado, the assumption being made that rainfall at this station follows as a general rule the fluctuations within the basin of the Cache la Poudre. It will be seen that the maximum amount of rainfall is in May, while the maximum river flow is in the early part of June. The rainfall in June decreases, and then increases slightly in July and August.

On the second diagram the mean discharge of the Rio Grande at Embudo, New Mexico, is compared with the mean annual rainfall at Santa Fe, although it is probable that the rainfall in the upper part of this basin has a habit intermediate between that at Denver and at Santa Fe. The river at this point reaches its maximum discharge earlier in the year than does the Cache la Poudre, and the rainfall, on the other hand, has its maximum in the early part of August.

In the third diagram the mean gauge height of the Colorado River at Yuma, Arizona, is shown in connection with the rainfall at Prescott, Arizona. The maximum river height is reached in the early part of June at the time of minimum rainfall in the basin, the maximum rainfall occurring about two months later, and usually causing little if any fluctuation in the height of the river.

The lowest diagram on the plate shows the average height of the lower San Joaquin River in conjunction with the mean rainfall at Modesto, California. Here the maximum discharge occurs at about the same time as that of Cache la Poudre Creek and of the Colorado River, while the maximum rainfall is about the first of January.

These four dotted lines of rainfall typify fairly well the distribution of rainfall in the arid region; on the east the maximum occurring in the summer, on the south the period of minimum rain occurring in May and June, and followed by heavy rain in July and August, at the time of the greatest droughts in California. The rivers, however, excepting in the case of those depending wholly upon local storms, have their regular spring floods independent of the distribution of rain.



AVERAGE MONTHLY RIVER FLOW AND RAINFALL.

RELATIVE AMOUNT OF FLOOD WATERS.

In any discussion of hydrographic data, and especially its bearing on water conservation, one of the facts of primary importance is the relation between the amount of water carried in floods and in low stages; in short, whether the river discharges in flood an amount greater by many times than that discharged during the remainder of the year, or whether the increase is comparatively small. For instance, taking a practical illustration, along most of the rivers of the West, as previously stated, is an area of land greater than can be irrigated during the latter part of the crop season, and with an unregulated flow the area of land to be cultivated is governed by the low-water discharge of the river; and furthermore, all of this low water has in most cases been long ago appropriated. To bring more land under cultivation it is essential, after practicing economy of the waters now available, to store some of the flood waters, and hold these until later in the season for use in time of need.

The question of primary importance, then, is the amount of flood water relative to the ordinary discharge—whether it is sufficiently great to insure the success of storage works, and in time repay the cost of their construction by permanence of supply; or, on the other hand, whether the floods are so small in amount or irregular in occurrence as to be of doubtful value. It is really upon the flood waters that the greatest dependence for storage must be placed, for in many parts of the country the low-water discharge being appropriated and used during the most important season of the year, little reliance can be had upon this low-water flow during the remaining seasons.

After the irrigating season is over, the amount of water flowing in the streams in the interval between that time and the beginning of the floods is usually small. In some parts of the country, especially in the south, the irrigating season extends practically throughout the year, and the water is used on the small grains, trees, and gardens, or for saturating the ground for the purpose of raising forage plants, when not otherwise needed. In many places, too, where the irrigating season is short, and extends only from four to six months, the water supply after the end of the irrigating season and between that time and the beginning of the floods is so small, or of such an uncertain character, as to be of doubtful value for storage purposes, the evaporation in many cases being sufficient to prevent an accumulation of water in any large storage basin. In short, then, it is to the amount and certainty of the flood waters that attention must be given in considerations of storage.

The relation between the quantity in flood and in low water is shown graphically upon the discharge diagrams or hydrographs of the various rivers, and it is instructive to compare these. The most conspicuous feature is the difference in character between the floods in rivers which receive their main water supply from melting snow and in rivers which depend wholly or in great part upon the rain fall. In the first case, as

shown by the hydrographs in the Upper Missouri basin, the flood is seen to consist of a gradual continuous rise, and to increase in quantity until a maximum is reached, followed by an almost equally continuous decline. In the latter case, for example in the Gila basin, the floods are of an exceedingly irregular character, coming at any stage of the river and passing off rapidly, the river falling immediately again to low stage.

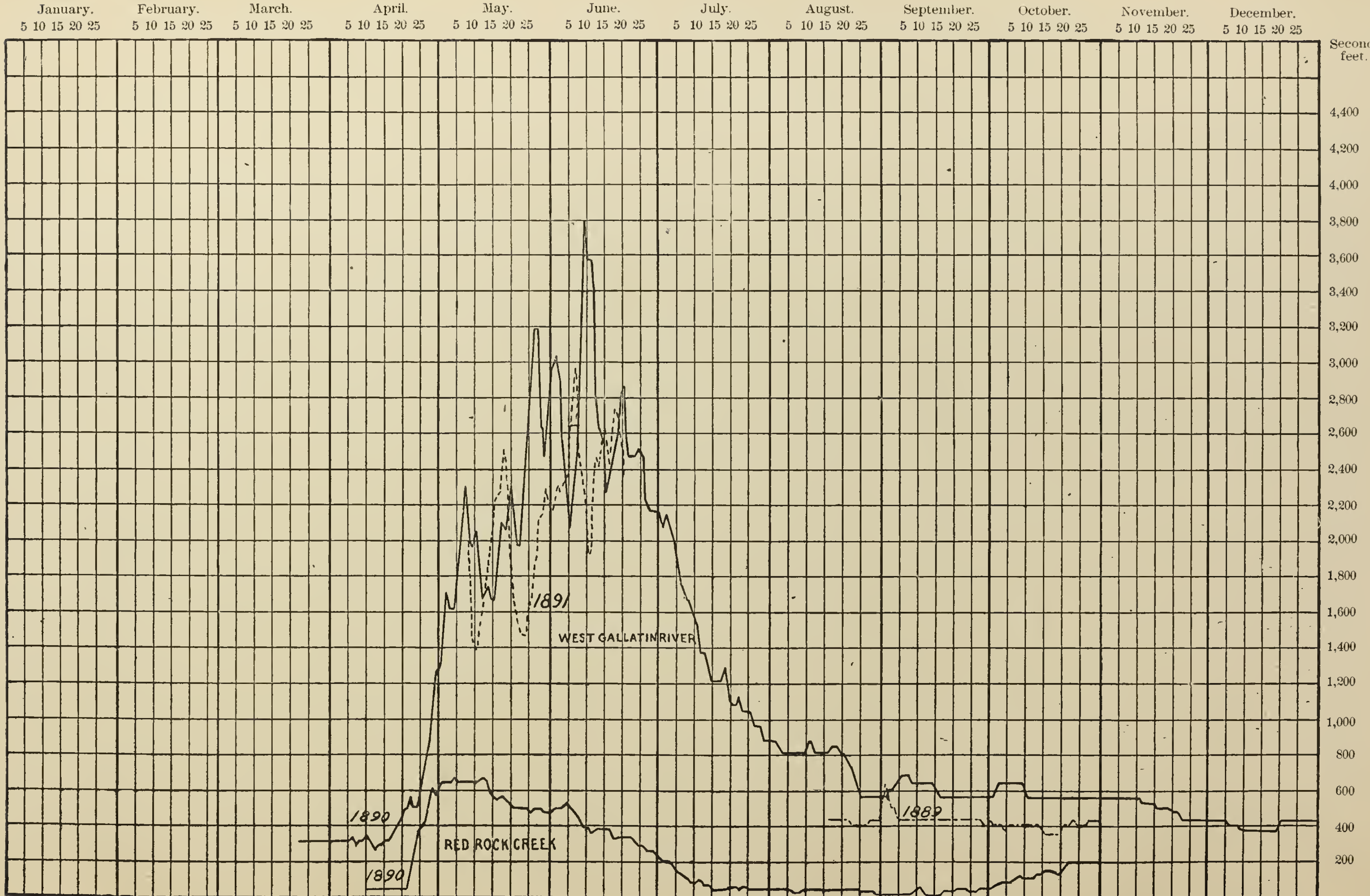
The following table is given in order to exhibit in concise manner the relation between the mean discharge and the quantity of water carried in floods during the years in which measurements have been made. In the column at the right is the quotient, obtained by dividing the maximum discharge by the average quantity flowing in the stream. For example, in the case of the first river on the list, the West Gallatin, the maximum flood reached a quantity four and five-tenths times the average annual discharge:

River.	Flood increase.	River.	Flood increase.
West Gallatin	4·5	Bear at Battle Creek	3·9
Madison	3·2	Bear at Collinston	3·2
Missouri	3·6	Ogden	3·4
Sun	5·9	Weber	5·4
Yellowstone	4·4	Provo	2·3
Cache la Poudre	1·8	Spanish Fork	6·6
Arkansas	5·3	Sevier	4·0
Rio Grande at Del Norte	4·7	Henry Fork of Snake	4·4
Rio Grande at Embudo	6·1	Falls River	3·7
Rio Grande at El Paso	11·1	Teton	4·3
Gila	12·6	Snake at Eagle Rock	5·3
Salt	100·0	Owyhee	6·8
East Carson	4·4	Malheur	6·3
West Carson	6·2	Weiser	6·8

On looking down the list, it will be seen at a glance that on most of the rivers the flood has been from four to five times the volume of the average flow for the year. The most notable exceptions, however, are in the case of the Rio Grande at El Paso, the Gila, and the Salt, where the measured floods were over eleven or twelve times the average flow, and on the Salt River one hundred times, this latter case being that of the great flood of February, 1891. It is probable that if the measurements were continued for a period sufficiently long a far greater flood increase would be noted on some of the other streams. The three instances just noted, however, stand out clearly as illustrations of the wide fluctuations of the rain-fed rivers of the south.

TIME OF FLOODS.

The fact of secondary importance to that of the quantity of the floods for storage is the time at which they occur and the relation between the duration of high water and the time of growing crops. On most of the rivers of the West floods occur in the spring and diminish in early summer. On some rivers they occur earlier and on others later, depending largely upon the altitude of the catchment basin. There is usually ample water at the time the crops are planted,



DAILY DISCHARGE OF THE WEST GALLATIN RIVER AND OF RED ROCK CREEK, MONTANA.

so that there is no trouble in giving a first watering to all the land cultivated, but toward the end of the season, when the crops are maturing, the supply in the river diminishes, and often a portion of the crop is lost from lack of water at the critical time.

As a rule it may be said that the later the floods occur the better for the success of crops and of storage schemes, for in the latter case the shorter is the time during which the water is held and the less will be the loss from evaporation. On the other hand, the earlier in the season the floods occur the less water will be available for crops and the greater will be the loss by evaporation.

The time is fast approaching when a large part of the flood water, excepting perhaps in a few great rivers like those of the Colorado drainage, will be held by storage from the early months of the year to July and August. In fact, much of this flood water is now needed, for the area of tilled land in many parts of the arid region is too great for the present supply in ordinary seasons, and unless some unusual storms occur, valuable areas of crops are lost. Besides these areas tilled, there are the tracts of fertile land so vast that the amount under cultivation shrinks into insignificance.

Comparing, therefore, the rivers in their adaptability for supplying storage reservoirs as regards the time of flood, it will be seen that the most favorable instances are afforded by the streams of the northern basins bounded by lofty mountains, as, for example, those of the upper Missouri and Arkansas basins, while, on the other hand, the streams draining the basins of less altitude are less favorable from this standpoint.

In strong contrast to the rivers flowing into the Missouri in regard to the time of flood are those of southern or lower basins, as, for example, the Gila and Salt, or the Malheur and Owyhee in Oregon. As will be seen at a glance at the diagrams for the Gila basin, the time of floods is very uncertain, and while, as a general rule, the floods are more apt to occur in certain months, yet they cannot be relied upon as in the case of most northern rivers. Water storage in these rain-fed rivers, therefore, becomes more a matter of chance, and it is not possible to estimate within as narrow limits as in the case of the snow-fed streams the probable amount of water to be obtained each year.

A comparison with the habits of the rivers outside of the arid region, as, for example, the Ohio or the Upper Mississippi, shows strongly the difference in the effect of the rainstorms, and illustrates the influence of topography and climate upon the discharge of a stream. On one extreme, that of the rivers in Arizona, the rain falls upon hard earth or barren rocks and slopes, which allow the water to flow off immediately. There is little or no vegetation to check or retain the water, and it rushes down the canyons and unites in the rivers, forming sudden floods. On the other extreme are the rivers of the humid region, rising in forested areas, where erosion has to a great extent cut down the higher moun-

tains into rolling hills now covered with vegetation. The rain is held for a time, at least, by the soil, and slowly finds its way to the river, and the flood rises gently and diminishes so gradually that the effect of a heavy rain may be felt for days or weeks.

INTENSITY OF FLOODS.

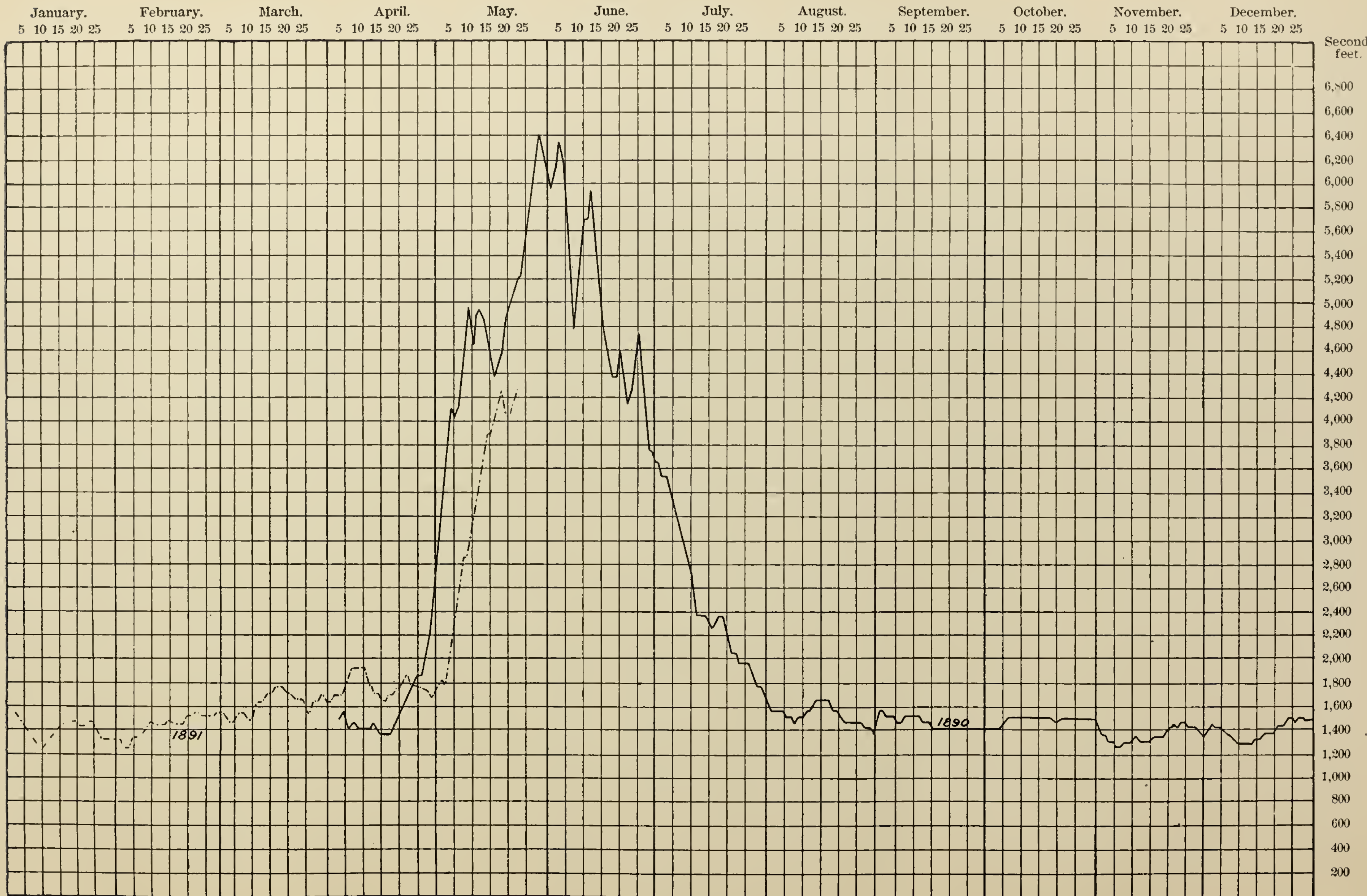
The intesity of floods—that is, the relation between the quantity of water and the time during which the flood occurs—is involved in the two points above mentioned. It follows as a matter of course that on those rivers on which floods occur suddenly the rate of increase of water will be greatest and its destructive effects most apparent. In proportioning storage works and canals for diversion of flood waters, intensity, as well as quantity of flood, plays an important part, for. on the one hand, structures must be designed to withstand the sudden impetus of floods, and, on the other, diversion channels or waste weirs must be made of extraordinary size to provide for the passage of enormous quantities of water in a few hours. It is apparent that structures to withstand the onset of floods, shown diagrammatically on many of the following plates, must be proportioned and executed in a manner which, to a person seeing only the low water, must seem extravagant.

One fact particularly characteristic of the regions of intense floods is that river channels in size and general appearance bear very little apparent relation to the average daily discharge of streams which flow in them. In humid regions from inspection of a river channel an engineer can, in general, form a valid opinion as to the average amount of water which flows in it and the probable extent of the floods, but in the arid region, especially in the basins of lost rivers, the size of channel is entirely out of proportion to the amount of water which ordinarily flows in it, due to the extremely erratic conditions which prevail. For years or decades there may be a mere rill or at places no water in sight in the natural drainage lines, when, by a sudden storm or local "cloud-burst," vast quantities of water will be precipitated, carving in a few hours a channel of capacity for a navigable river. Thus it is that long observations are required to determine what may be the average flow of streams of this class and the quantity of water, if any, which can be depended upon from year to year.

RAINFALL AND RIVER FLOW.

The amount of water flowing in the river each day does not depend directly upon the rainfall of the preceding days, but upon many modifying conditions, and a storm, although widespread and reported at all stations, may not show itself by greatly increasing the amount of water passing any given point on the river. On the other hand, a storm so local that it is not reported by observers may cause a decided increase in the amount of water available, or even a destructive flood.

In examining the depth of run-off—that is, the quantity of water dis-



DAILY DISCHARGE OF THE MADISON RIVER AT RED BLUFF, MONTANA.

charged equivalent to a certain depth over any given basin—it will usually be seen that the larger the area the less is the relative amount discharged, and this is especially the case in those parts of the country where evaporation is notably greater than rainfall. The rivers increase in size to a certain point as they flow down the broad sandy channels, and then decrease, excepting in times of unusual floods. Even in those parts of the country where rainfall is great and evaporation of less importance this general law seems to hold good, namely, that the rivers do not increase in volume in direct proportion to the area drained, but that the ratio of discharge to area is, in a general way, decreasing from the headwaters toward the outlet. This fact must be borne in mind in these comparisons, and due allowance made for the point on the river's course at which measurements are made.

POINTS OF MAXIMUM UTILITY.

There is a general similarity among the rivers under discussion in that they rise in great mountains and flow as torrents through narrow valleys, gorges, and canyons, entering finally upon plains of vast extent and with nearly level surfaces. On account of the great altitude the sources of the river are usually in a cold and an inhospitable region where great bodies of snow accumulate during the winter, and the frosts, which occur perhaps every month of the summer, render agriculture entirely out of the question. Below this upper region are often valleys which, though still of considerable altitude, are suitable for grazing, and in which a few of the hardier crops can be raised. Here also is found the most valuable timber, and the climate, though rigorous, is favorable for habitation, so that settlers, if forced from the lower regions from lack of water or other causes, find here place for homes and opportunities for earning a livelihood. These valleys also are most favorably situated for storage reservoirs, many of glacial origin seeming to be thus designed by nature.

Farther down, beyond the canyons, stretch the wide, open valleys, and out beyond these the rich alluvial soil of the plains. It is here at these lower altitudes with a warm, sunny climate that agriculture is most successful, and here a given amount of water properly used will raise crops of the greatest value. In these places, near the foot of mountains, the water flows in well defined channels with high confining banks. Farther out upon the plains, however, the character of the river and its channel change. The silt deposited by the diminished velocity chokes the bed of the river, and the water spreads over a great expanse of sands, dividing and subdividing into numerous shallow streams whose united width may be more than a mile, but whose depth at ordinary stages is scarcely over a foot. In these sands enormous quantities of water disappear by seepage and evaporation, until finally, in seasons of low water, the channel becomes almost if not completely dry. The conveyance, therefore, of water through this channel to land far out

on the plain involves a wasting of the greater portion in order that a small part may reach the desired locality.

From the above considerations alone it will be seen that the point from which water can be used to the greatest advantage is that at which the stream begins to change in character, to lose its well defined channel and sink in the sand of the bed, for at this point the river is carrying its maximum amount of water. The land here is usually as fertile as any on the plains, while the opportunities for canal building in the gently sloping edges of the plains are most favorable both for taking out the water at the smallest cost and for covering the largest extent of land.

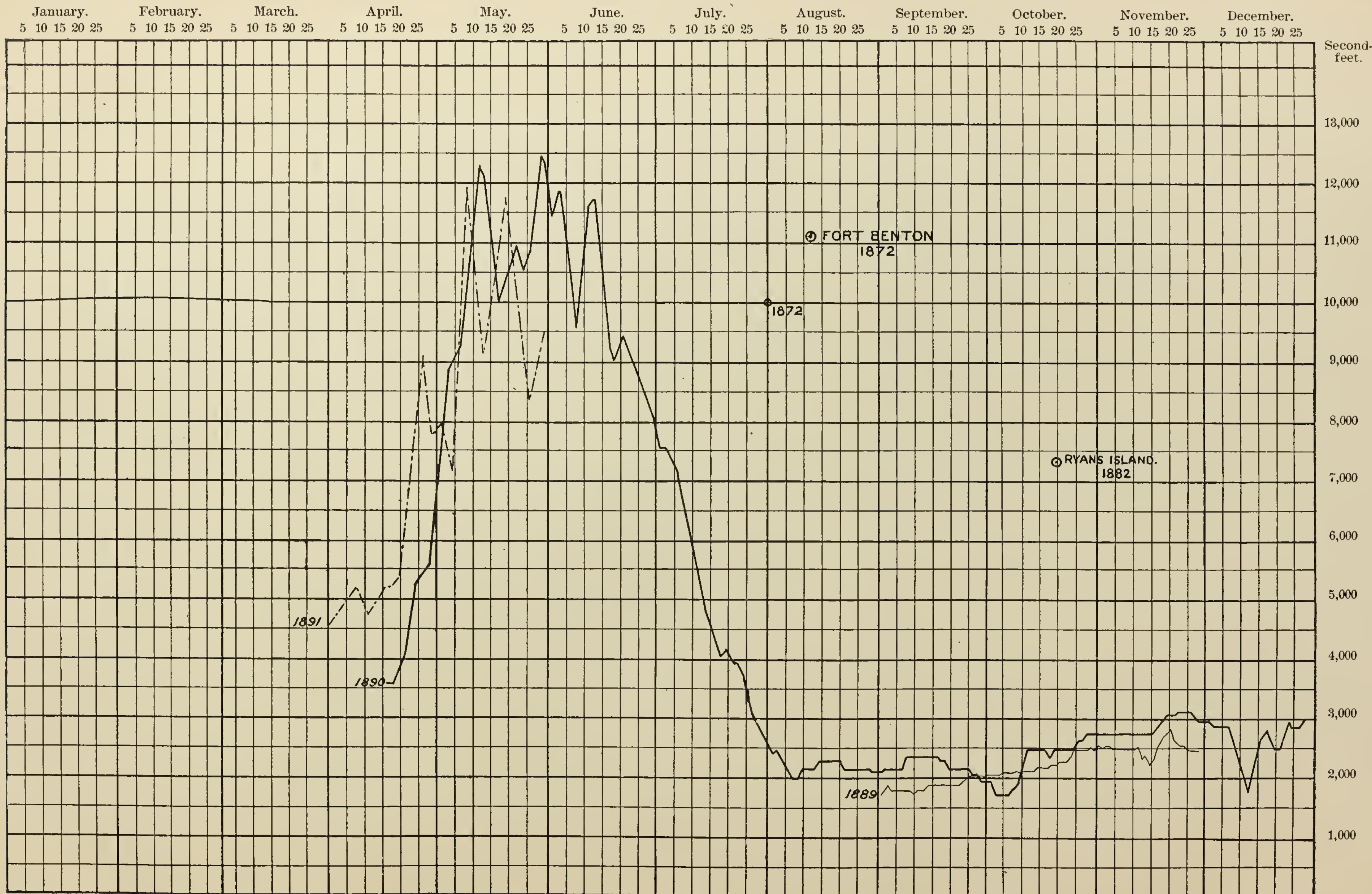
If the water is diverted far above this point it is used with less economy and, on account of the altitude, the crops raised are of less value, while below this point on the open plain the wastage of water required for its conveyance in sandy channels results in loss, which is in general proportional to the distance to be covered. The chief interest, therefore, centers on the examination and measurement of the streams as they leave the canyons, and, secondary to this, on similar work in the upper valleys, where the great storage sites are found.

CLASSIFICATION OF DRAINAGE BASINS.

Hydrographic basins are divided by Powell into three classes, viz: Headwater districts, river trunk districts, and lost stream districts. The headwater districts include the sources of the river in the high mountains, including thus the torrential portion, and also the land used for farming immediately adjoining the river where it leaves the mountains. In a large river system this is the most important and most interesting portion of its course, from the standpoint of irrigation. Each large perennial tributary of the river thus becomes a district by itself, and can be considered independently in any discussion of the hydrography of the region.

The river trunk district includes the great area through which the main stream flows, but from which the stream receives little or no water. This vast area, in fact, instead of contributing to the flow, leads only to its dissipation, for, in passing through the wide valleys or plains which constitute this portion, much of the water is lost by seepage and evaporation. The trunk stream district can not be considered by itself, but must be governed largely by the conditions existing in all of the headwater districts, and it is only after the problems connected with the headwaters have been satisfactorily settled that the main stream can be treated in the best manner.

The third class of basin, which in the west is one of the most important and perhaps most easily controlled, is that of the lost river. In this the circulation of waters is complete within itself, that is, the water coming from the atmosphere in the form of rain or snow gathers on the mountain slopes and flows in torrents to the plains, where it again dis-



DAILY DISCHARGE OF THE MISSOURI RIVER AT CRAIG, MONTANA.

appears, finally returning to the air by evaporation. Thus each basin can be considered independently, since the proper utilization of its waters does not effect any other basin except in the most remote manner.

All these classes of basins are represented in many of the great river systems, in the Arkansas, the Rio Grande, the Gila, and others, each embracing within its scope many minor basins, some tributary to the river and others entirely lost. Each of these subbasins constitutes a unit, and, while the lost river basin may be considered as an independent unit, the others are factors, upon the proper application of which depends the final solution of the problem as to the best manner of utilizing the water supply. Each one must be carefully studied in turn, its limits clearly defined, and all the characteristics known. Within each of these basins the problems of water supply are to be studied for the whole area, as each part is intimately connected with every other, and whatever affects one locality influences the rest. A storage work built on a minor tributary, since it tends to diminish the water at one time and increase it at another, is of importance to the majority of inhabitants of that particular basin. Considering all the subbasins, the influence of one upon the other varies with their character. For example, the headwater basins, as a whole, must be considered in connection with works of improvement on the trunk-stream basins, while, on the contrary, the lost-stream basins, being units which stand entirely independent of the rest of the country, need less consideration, excepting as they may influence the wealth and population in a general way.

The headwater and lost-stream districts are easily recognized, being plainly marked by nature and separated from each other by mountain ranges or lower divides shown by the topographic maps. The main-stream districts, however, are not so clearly delimited, for the lines bounding them are somewhat arbitrary in their nature, so that careful study must be given to the conditions which govern them.

The lost rivers, though found scattered throughout the west in nearly all of the large drainage basins, are most numerous and in fact are distinctive of the great interior basin. Within this area not a drop of water escapes to the sea; the rain descending upon the mountain flows for a time in streams, then finally passes into the air again, is carried by the wind, which perhaps striking against some great escarpment is deflected upward and the moisture again precipitated enters upon a new round of river life, this round being repeated again and again, the individual molecule of water perhaps passing through innumerable changes of condition, until finally it travels out of the basin to be replaced by moisture which is continually entering, mainly from the Pacific side. In this round of existence a portion of the moisture is caught and held for an indefinite time in the sands or gravels of the river bottoms which are saturated by percolation from the running streams. These layers of porous material form reservoirs from which wells and springs are supplied, the amount of water delivered by these wells and

springs being in a general way proportional to the extent and permeability of the sands and gravels.

HUMIDITY AND IRRIGATION.

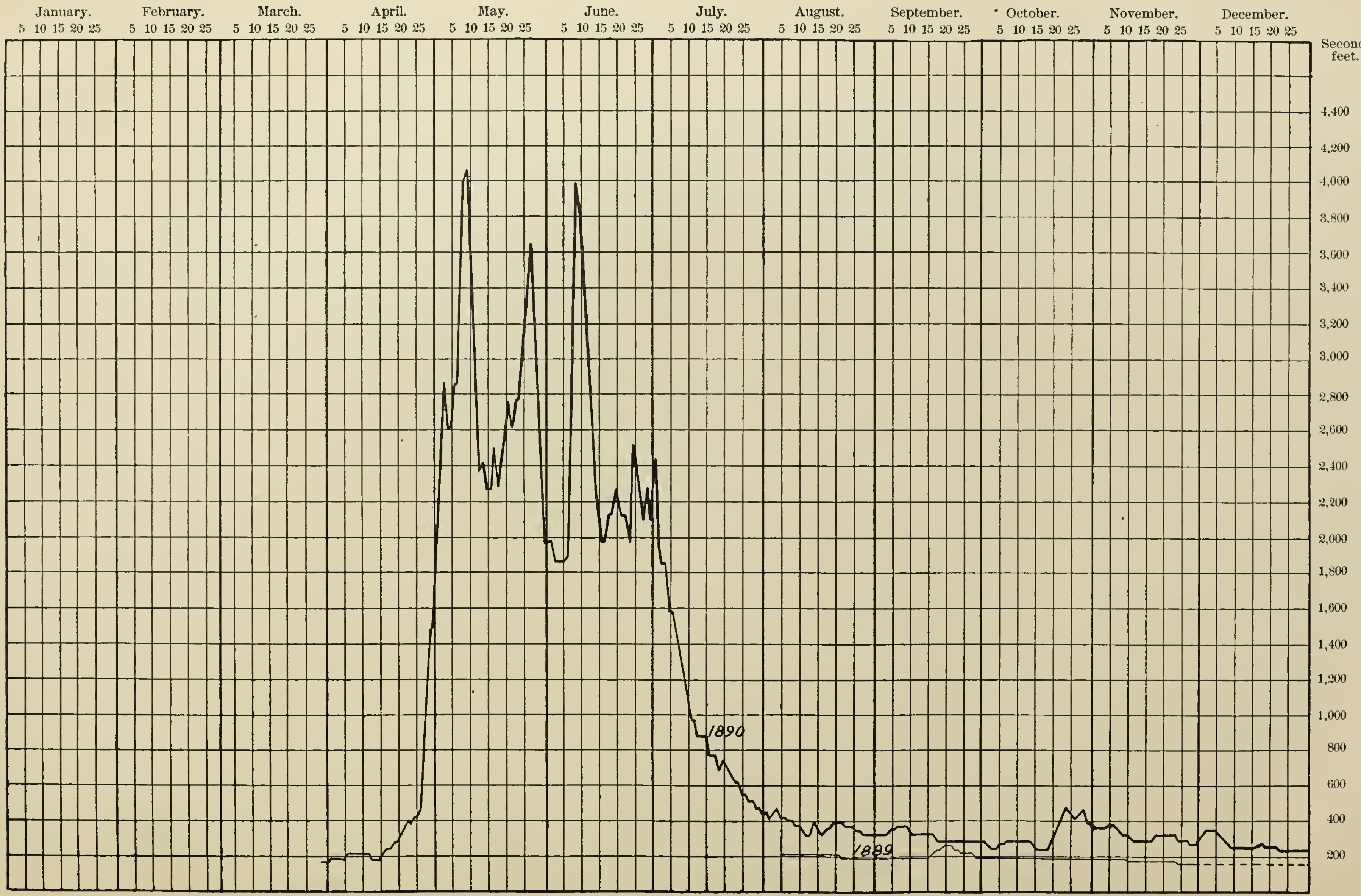
There is a popular belief that by spreading the water on the surface of the ground through irrigation the rainfall is increased by the addition of this water to the air through evaporation. There is no question that evaporation from the soil, especially from large tracts of cultivated land, must tend to lower the temperature near the surface and make the air far more humid, so that, as far as the feelings or sensations of man go, irrigation and consequent evaporation may tend to modify the temperature and make it better adapted for the comfort of man in the immediate vicinity of his operations. But, as for modifying the climate as a whole or bringing about such changes as will cause an increased rainfall, it is doubtful if these operations can have the slightest influence, especially if the relative bulk of water contained in the air is compared with that which is added to the ground and escapes by evaporation, to increase the amount and percentage of that already there.

In this connection it is interesting to note that inland lakes, with their vast bodies of water continually adding moisture to the air, increase the rainfall only to a slight extent, if any, around their borders. If these vast stretches of water do not have a decided and perceptible influence upon the rainfall of a country, it seems hardly possible that the smaller scattered areas of earth moistened by irrigation, in extent hardly 1 per cent of the entire area of any one county, can have any measurable influence upon the distribution of rain. The benefits to be derived are, however, not dependent upon increasing the humidity of the atmosphere as a whole, but only of that minute fraction of it which happens to be in immediate contact with the parts of the earth's surface utilized by man.

In short, in all water conservation, the first efforts should be directed toward making the largest use of the present available moisture, preventing losses by evaporation not only in the flowing water, but in the fields, by means of proper tilling and by sheltering the soil, and after that by increasing the available supply by storing floods, and by making use of other sources which require engineering skill and the investment of capital.

EVAPORATION OBSERVATIONS.

The evaporation observations described in the previous annual report have been continued in the same manner at Fort Douglas, the military post near Salt Lake City, Utah, at Fort Bliss, about a mile above El Paso, Tex., and also at Tempe, Ariz. The results obtained at these three places, together with those of previous years, are given in the following table.



DAILY DISCHARGE OF THE SUN RIVER 18 MILES ABOVE AUGUSTA, MONTANA.

Monthly totals of evaporation from large pans.

Months.	Fort Douglas, Utah.			Fort Bliss, Texas.			Tempe, Arizona.		
	1889.	1890.	1891.	1889.	1890.	1891.	1889.	1890.	1891.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	....	....	....	....	2.0	2.7	....	....	3.9
February	....	....	....	....	2.0	2.9	....	....	3.6
March	....	....	....	....	7.0	5.5	....	....	3.7
April	....	3.7	3.2	....	7.3	7.4	....	5.8	4.2
May	....	4.1	4.8	10.9	10.8	....	....	5.5	....
June	....	5.1	5.2	10.7	11.7	....	....	5.6	....
July	....	7.6	7.6	9.6	9.6	....	13.7	6.6	....
August	10.5	6.5	6.5	11.4	7.6	....	14.1	11.5	....
September	5.7	4.6	5.2	9.2	....	....	11.0	5.8	....
October	4.9	2.1	2.5	6.8	....	....	6.4	5.2	....
November	1.0	1.2	1.4	4.6	3.7	....	4.4	4.6	....
December	....	....	....	2.9	3.0	....	....	3.2	....

RESULTS OF STREAM MEASUREMENTS.

In the following pages the data for the various drainage basins are presented in geographical order, beginning at the headwaters of the Missiouri and continuing southward, taking in turn the Yellowstone, Platte, Arkansas, Rio Grande, and Colorado River basins, then the San Joaquin and Sacramento, the Interior Basin, and finally the Snake drainage. In each of these the order of arrangement is from the headwaters toward the mouth. In the case of the Rio Grande, Gila, and Salt Lake basins a description of the topography and its relation to the water supply is given with some degree of minuteness.

Descriptions of the gauging stations, and the results of the measurements in these basins up to June 1890, have been published in the Eleventh Annual Report of the Director of the U. S. Geological Survey, Part II, together with comments upon the local topography and climate. Since the time of that publication readings of gauge height have been maintained at the principal localities mentioned in that report, enabling computations to be made of the daily mean discharge at those places, thus affording opportunity for comparison of the amount of water flowing in the years 1889 and 1890.

The daily discharges of the streams measured in these basins are shown in diagrammatic form on the accompanying plates. The irregular lines indicate by their position the amount of water flowing on each day of the years given. The days are indicated by the spaces from left to right, in general each fifth day of the month being designated by a vertical line. The amount of water flowing on intermediate days can be ascertained by dividing these spaces by the eye into fifths. In the case of the months having thirty-one days the space from the twenty-fifth day to the first of the next month is proportionally wider than the others, and in the case of the last three days in February proportionally narrower.

The height of the curved line above the base indicates the average amount of water in cubic feet per second flowing on the particular day considered. Thus these diagrams show not only the amount of water on any given date, but also the amount relative to that of the whole year or series of years, and to that of other rivers. The average

monthly discharges, or at least such as have not been published in the previous report, are given in condensed form at the conclusion of this paper.

UPPER MISSOURI AND YELLOWSTONE.

On Pl. LX the discharges for the West Gallatin, southwest of Bozeman, Montana, and for Red Rock Creek, a tributary of the Jefferson, are given together, since the discharge of the latter is so small that it does not interfere with the clearness of the diagram. The discharges of the West Gallatin during September and October of 1889 are given, being indicated by a line of dots and dashes. This discharge, as can be seen, was nearly 200 second-feet less than in the succeeding year. The measurements in 1891, beginning in the early part of May, show a less discharge than that of 1890.

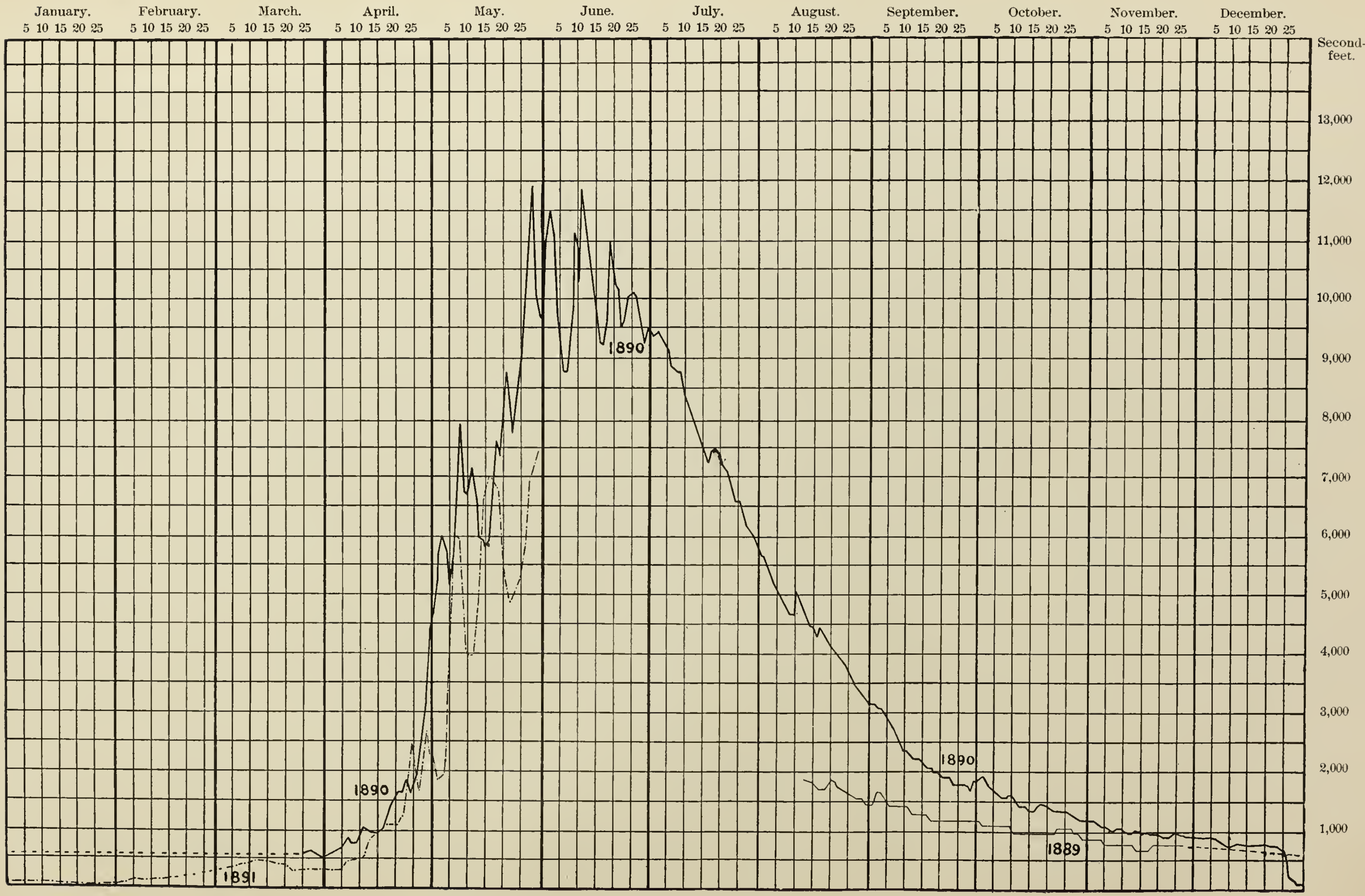
The discharge of the Madison, near Red Bluff, Montana, is shown on Pl. LXI, the most noticeable feature being the comparative regularity of the small oscillations during all the months of the year excepting those of the spring floods. The discharge of 1891, as in the case of the other rivers, is decidedly less than 1890.

The amount of water in the Missouri River at Craig, as shown on Pl. LXII, is in 1891 nearly equal to that of 1890, the lower discharge of the tributaries, however, being noticeable even in the case of the main stream. The relative location of these stations can be seen on the small map, Pl. LVIII, which also gives in a general way the relative size of the areas drained.

The discharge of the Sun River above Augusta, Montana, is shown on Pl. LXIII. A record has been kept of only one flood season, that of 1890, and therefore comparisons can not be made. It is probable, however, that this series of measurements represents fairly well the ordinary behavior of the river. The low water of the fall of 1889 is shown on the diagram, it being in amount decidedly less than that of 1890.

It is interesting to compare the results given on the diagrams and in the tables with those obtained in other years. The earliest recorded gangings were made in 1872 by Thomas P. Roberts, assistant engineer on the Union Pacific Railroad.[1] He found that the Gallatin was flowing in the latter part of July, 1872, at the rate of 2,090 second-feet, the Madison 2,670 second-feet, and the Jefferson 3,778, making in all 8,538 second-feet. According to Roberts's judgment, the lowest water of September and October was about 6,600 second-feet, and the highest in the middle or last of May, 33,300 second-feet, both amounts being, however, far greater than obtained by later measurements. On July 31, 1872, the measured discharge at a point 71 miles below the Three Forks was 10,000 second feet, and on August 12, at Fort Benton, 11,132

[1] Report of a Reconnoissance of the Missouri River in 1872, by Thomas P. Roberts, assistant engineer Union Pacific Railroad. Printed for the use of the Engineer Department, U. S. Army, 1875.



DAILY DISCHARGE OF THE YELLOWSTONE RIVER AT HORR, MONTANA.

second-feet,[1] the amount of these discharges relative to the results obtained by recent measurements being shown on Pl. LXII.

In 1882 gaugings were made by the Engineer Corps, U. S. Army, at Stubbs Ferry, 73 miles below the Three Forks, and 12 miles from Helena, and of the three principal tributaries entering below Stubbs Ferry. The discharge at this place was, at a stage of 0·5 feet, 3,770 second-feet; of the Dearborn, at high water in the Missouri, 622 second-feet; of Deep Creek, at 2·75 stage of Missouri, 1,800 second-feet, and of the Sun River, at 3·05 feet in Missouri, 4,270 second-feet. The total discharge of the Missouri just below the mouth of the Sun River, or about 50 miles above Fort Benton, was, for a stage of 3·05 feet, 19,425 second-feet.[2]

In 1878 a gauging was made at Dauphin Rapids, 95 miles below Fort Benton and about 12 miles below Judith River. The discharge was 11,062 second-feet[3] from a drainage area of 39,247 square miles.[4] It was estimated that the mean daily discharge in 1879 was 13,530 second-feet, and in 1880 was 18,151 second-feet. Comparing this with the mean annual rainfall in these years, which was assumed to be 15·80 inches and 16·88 inches, respectively, in the basin, the run-off was computed to be 30 per cent of the rainfall in 1879, and 37 per cent in 1880,[5] or a depth of 4·67 inches and 6·30 inches in these respective years.

On October 20, 1882, a measurement was made at Ryan Island, 72 miles below the above-mentioned locality, and about 30 miles above the mouth of the Musselshell River, the drainage area being estimated to be 39,965 square miles. The discharge was 7,305 second-feet at a stage of 0·87 foot above low water of 1874.[6]

In the fall of 1890 a few stream measurements were made by Mr. G. A. Marr, assistant engineer of the Missouri River Commission, while carrying on careful leveling from Three Forks to Fort Benton, Montana. These gaugings, although considered approximate merely, are given in connection with other data, because they afford material for further study. The first of these is the measurement of July 28, 1890, made above the Three Forks, when it was found that the Gallatin discharged 730 second-feet and the three streams—the Gallatin, Madison, and Jeferson—aggregated 2,863 second-feet. The second measurement was on August 6, 1890, on the Missouri, just below Gallatin, the total discharge being 2,460 second-feet, and the third on September 18, 1890, near Canyon Ferry, giving 2,682 second-feet.

The daily discharge of the Yellowstone River below the National Park is given in graphic form on Pl. LXV. The measurements were made about 6 miles below the town of Cinnabar, at Horr, a station described in a previous report. As shown on this plate, the discharge for 1891 is similar to that for 1890, but is, in general, a little less.

[1] Report of a reconnoissance of the Missouri River, etc., p. 54.
[2] Annual Report of the Chief of Engineers, U. S. Army, 1883, p. 1340.
[3] Ibid., 1878, p. 699.
[4] Ibid., 1883, p. 1353.
[5] Ibid., p. 1353, et seq.
[6] Ibid., p. 1354.

Many of the tributaries of the Yellowstone, especially those heading in Wyoming, are of great importance in irrigation, their waters in the summer being entirely diverted upon the fertile lands along the valleys. The State engineer of Wyoming, under authority of recent legislation, has gauged some of these streams for the purpose, primarily, of obtaining information by which to determine the rights of the various canals and ditches claiming the waters. In this manner a body of data is being acquired concerning these tributaries, which, however, has not as yet been published. For example, a permanent gauging station has been established on Clear Creek, near Buffalo, Wyoming, this stream, a tributary of Powder River, supplying water for a part of one of the most important agricultural areas in the State. In the annual report of the State engineer for 1890 it is stated that, upon explaining to some of the public-spirited citizens of that vicinity the importance of a gauging station and the inability of the engineer to establish it on account of the lack of appropriation from the State, the citizens immediately volunteered to assist in the work, and an arrangement was made by which they undertook the construction of a weir. Pending the completion of the weir, a temporary gauging station was established, and daily readings are taken of the discharge of the stream.

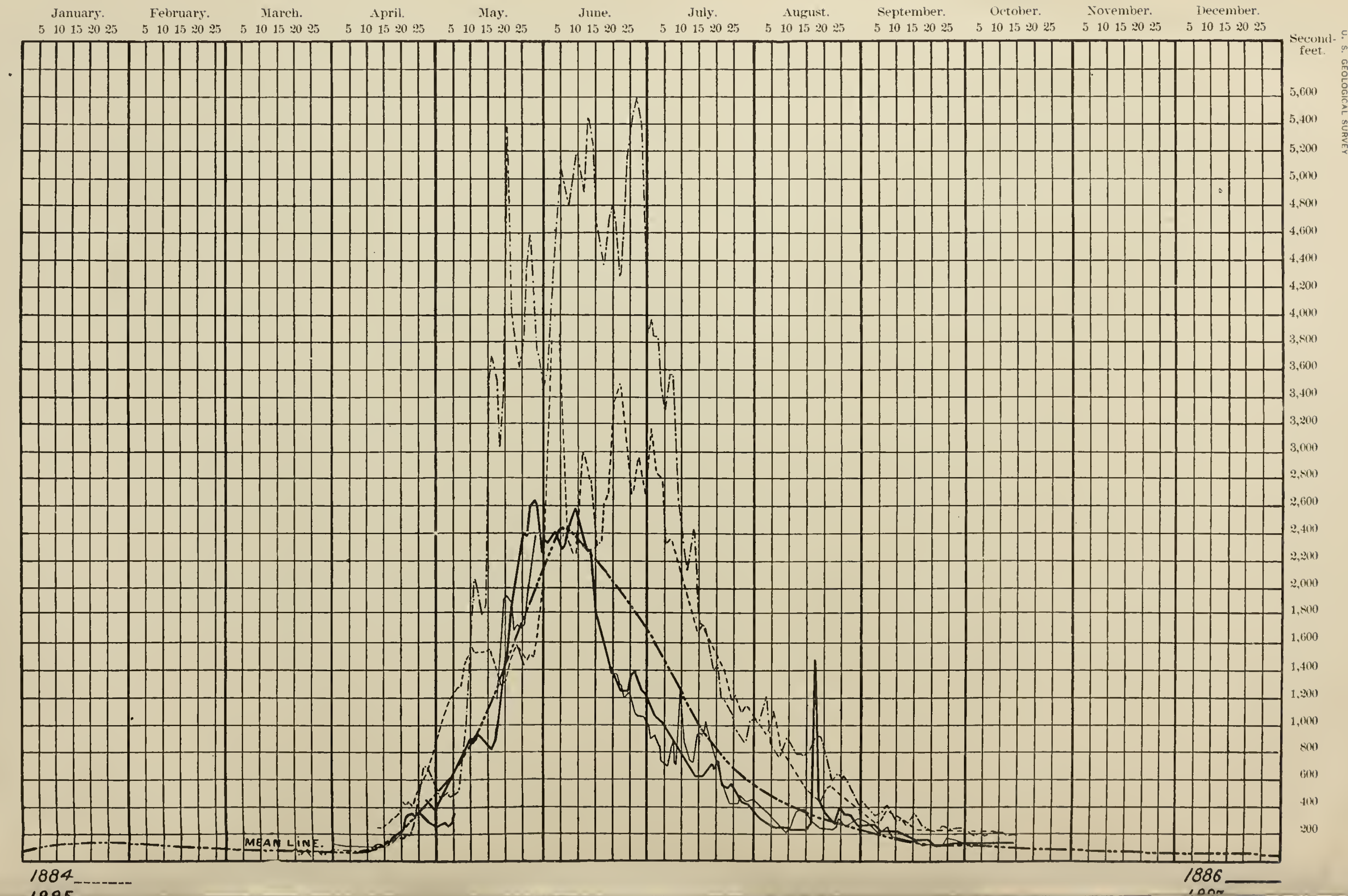
The discharge of the Yellowstone was measured in August, 1879, at the mouth of the Big Horn, at a stage of 1·70 feet above low water of 1878, giving for the Big Horn 5,865 second-feet, for the upper Yellowstone 7,471 second-feet, and total discharge below the Big Horn 13,336 second-feet. At Fort Keogh, 100 miles by river below the Big Horn, the discharge in September, 1878, was 14,462 second-feet, in October, 1879, was 6,505 second-feet, and in 1883, at about the same stage, 6,015 second-feet. At Wolf Rapids, 50 miles below, in September, 1878, gaugings gave 11,235 second-feet, and at Diamond Island, 100 miles by river below Wolf Rapids, in October, 1878, the discharge was 8,155 second feet.[1]

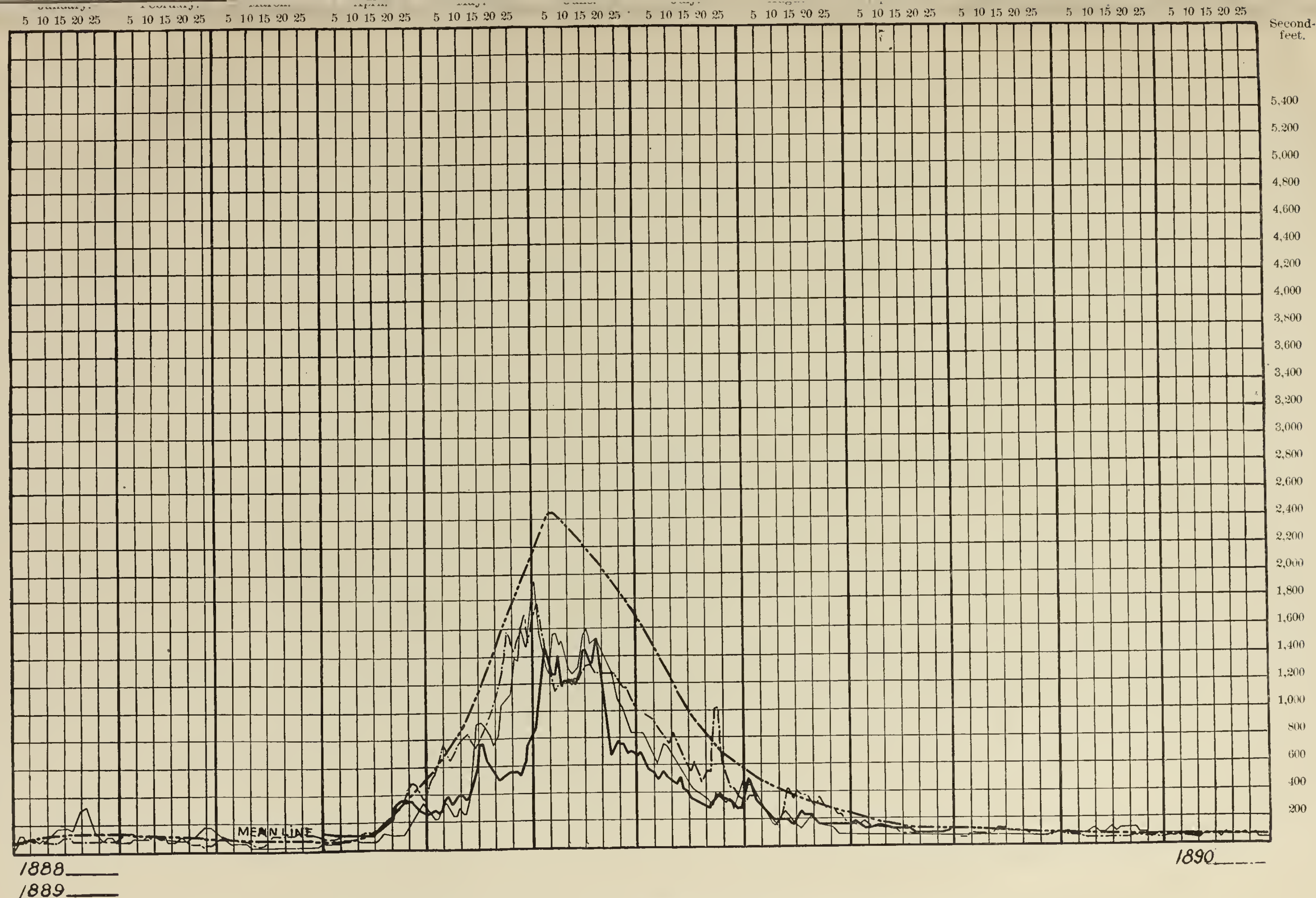
The total drainage area of the Yellowstone is 69,683 square miles, and of the Missouri, above the mouth of the Yellowstone, 95,093 square miles. The data for the total discharge of the Upper Missouri and Yellowstone are not sufficiently extended to enable exact comparisons to be made, but from inspection of the foregoing it appears that the quantity of water in the two streams is about equal.

PLATTE BASIN.

The most important series of measurements in this drainage basin are those being made on the Cache la Poudre, about 12 miles above Fort Collins, Colorado. These have been fully described in the previous report, and the results given up to June 30, 1890. The diagrams on Pl. LXV show graphically the daily discharges up to the present time and afford a means of comparing one year with another.

[1] Annual Report of the Chief of Engineers, U. S. Army, 1880, p. 1476, and 1883, p. 1342.


January. February. March. April. May. June. July. August. September. October. November. December.
5 10 15 20 25
Second-feet.
5,600 5,400 5,200 5,000 4,800 4,600 4,400 4,200 4,000 3,800 3,600 3,400 3,200 3,000 2,800 2,600 2,400 2,200 2,000 1,800 1,600 1,400 1,200 1,000 800 600 400 200
MEAN LINE.
1884
1886



DAILY DISCHARGE OF THE CACHE LA POUDRE 12 MILES ABOVE FORT COLLINS, COLORADO, 1884 TO 1891.

For clearness these data have been placed on two diagrams, the discharges for 1884, 1885, 1886, and 1887 being placed on one page, and those for 1888, 1889, and 1890 on the other. In addition to these discharges for individual years, the line showing the average daily discharge has been plotted on both diagrams. This curve shown by heavy dots and dashes has been obtained by combining the results for each year since the beginning of the observations. The discharges for 1884 and 1885 come far above this line, while those for 1886 and 1887 agree with it fairly well. During the years succeeding these, however, the flood discharge does not at any time reach this line, showing the great diminution in flow for the last three years.

The fluctuations and uses of the waters of the Cache la Poudre are discussed by Prof. L. G. Carpenter in the annual reports of the Colorado State Agricultural College at Fort Collins.[1] Other measurements of flowing water have been made at various points in the Platte basin, these, however, being mainly disconnected and fragmentary. Mr. Henry Gannett, in the Hayden[2] report for 1876, gives the results of a number made on tributaries heading near the continental divide. The State engineer of Wyoming has also made a number of gaugings of the Laramie and other rivers, and has established gauging stations, the results of which promise to be of value.

A permanent station on the Laramie was established in December, 1888, at Woods, near the southwestern corner of Albany County, about 30 miles above Laramie City. During the following winter and up to April 1, 1889, the discharge was approximately 112 second-feet. The maximum for the year, 1,620 second-feet, occurred in June, falling from this to a minimum of 43 second-feet in September. A smaller quantity of water was discharged in that year than ever before known, the maximum in some seasons being over 6,000 second-feet.

The North Platte was gauged by Mr. A. M. Van Auken, civil engineer, near Fort Laramie, Wyoming, in 1887, 1888, and 1889, and also near the Wyoming-Nebraska line during the low stages of 1890, the velocities in each instance being obtained by means of floats. The results are not considered by him to be more than approximations, but as such they have their value, and with this qualification they are herewith given. It is believed by Mr. Van Auken that these figures will give a fair idea of the discharge of the stream, and that the results are more accurate for the smaller discharges than for the larger.

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[1] The State Agricultural College of the State of Colorado. Third annual report of the agricultural experiement station, 1890. Fort Collins, Colo., p. 58.

[2] Tenth Annual Report of the U. S. Geol. and Geog. Survey of the Territories, F. V. Hayden. 1876, pp. 323–326.

North Platte River.

Month.	Discharge.			Month.	Discharge.		
	Max.	Min.	Mean.		Max.	Min.	Mean.
1887.	*Sec. f.*	*Sec. f.*	*Sec. f.*	1889—Continued.	*Sec. f.*	*Sec. f.*	*Sec. f.*
May	8,240	3,520	5,255	June	10,260	5,170	8.240
June	10,140	7,680	8,995	July	6,080	4,240	5,506
July	7,680	3,640	5,676	August	4,290	3.220	3,498
August	3,720	3,380	3,560	September	3,240	2,580	2.892
1888.				October	3,210	2,430	2,859
May	4,510	3,780	3,991	November 1 to 15	3,960	2,370	3,205
June 1 to 21	6,490	3,920	5,671	1890.			
July 11 to 31	6,060	4,280	4,711	March	3,400	3,180	3,316
August	5,180	3,900	4,341	April	3,720	3,200	3.457
September	3,920	3,430	3,822	May	6,970	3,840	5,151
October 1 to 22	3,920	3,110	3,517	June	10,240	8,180	8,682
1889.				July	7,960	5,120	6,469
April	3,438	2,970	3,208	August	5,425	3,380	4,160
May	8,120	2,960	4,216	September 1 to 6	3,680	3,440	3,560

ARKANSAS BASIN.

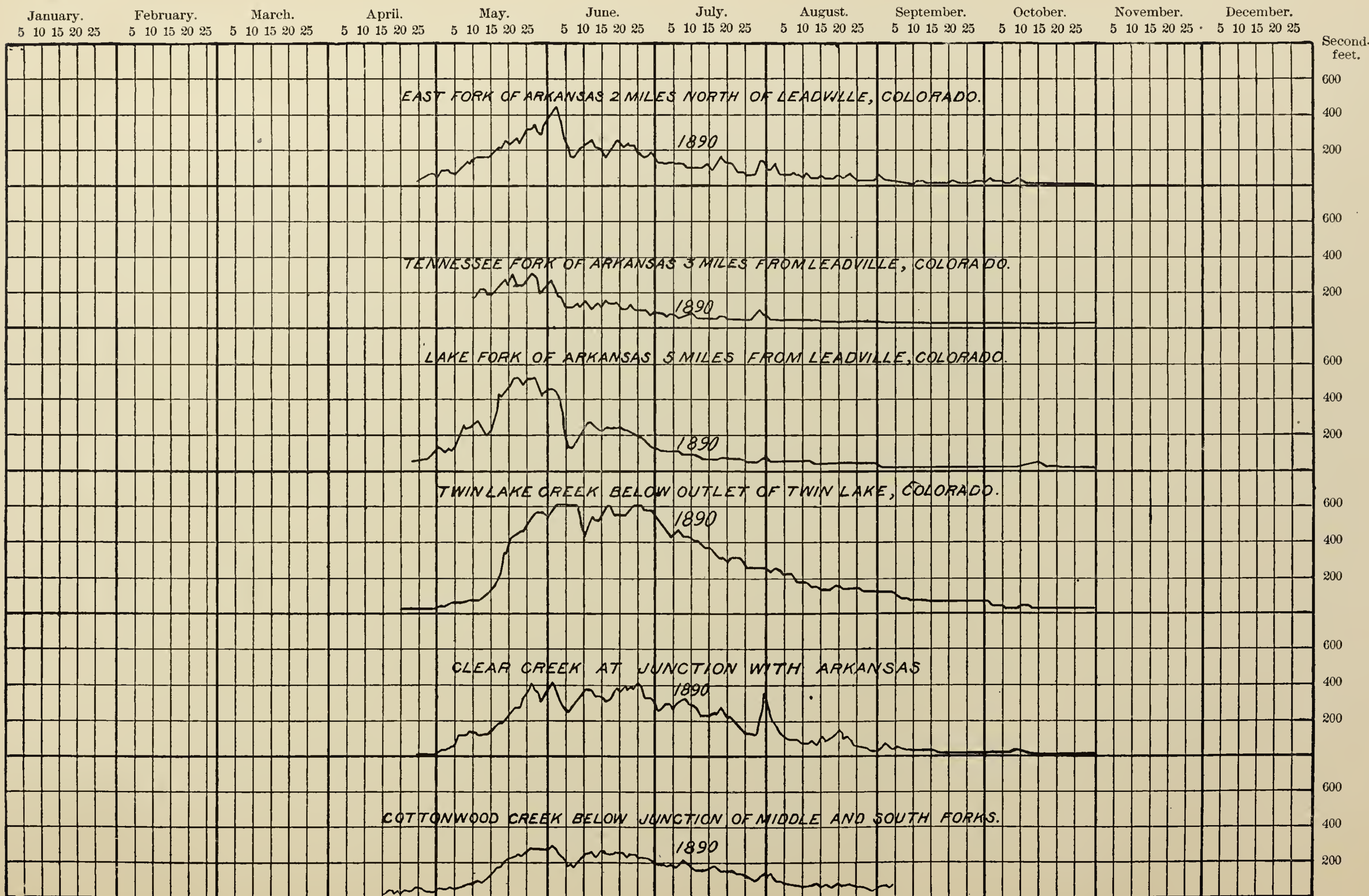
The gauging stations in this basin were described in the last annual report of this Survey, to which reference should be made for details regarding the measurements up to that time. The results of these measurements and computations of discharge for the upper tributaries of the Arkansas are given on Pl. LXVI, and for the Canyon City station on Pl. LXVII. Referring to this plate, it will be seen that the most notable fact is the increased discharge during the spring of 1891. This is also brought out by the table of monthly discharges given on page 349. No measurements have been made of the discharge at stations on the lower Arkansas since 1889. The gauge heights at these stations have been published in diagrammatic form in comparison with the rainfall in the basin in the previous annual report. (Pl. LXXI. Eleventh Ann. Rep. U. S. Geol. Survey, part II.)

RIO GRANDE BASIN.

TOPOGRAPHY AND ELEVATIONS.

A study of the hydrography of the Rio Grande Basin, Pl. LXVIII, and of its facilities for water conservation offers some of the most interesting problems undertaken by the Geological Survey. This is due not only to the large extent of area covered by this basin, but also to the wide difference in topography and character of soil and climate. The matter is further complicated by the relation of political divisions, State and county lines, to the basin as a whole.

This discussion of the Rio Grande Basin, including the subbasin of the Pecos, its largest tributary, is confined to that portion lying within the State of Colorado and the Territory of New Mexico, the part in Texas possessing a smaller interest in this connection. The total area in these three political divisions above the junction of the Pecos with the Rio Grande is, approximately, 145,200 square miles. Not all of the area embraced within the limits of this great topographic basin contributes water to the river, but on the contrary, there are extensive



DAILY DISCHARGE OF THE UPPER TRIBUTARIES OF THE ARKANSAS RIVER, 1890.

tracts, as in the case of all the southern basins of the arid region, from which there is no outflow. The total area north of the Texas-New Mexico line, including the lost river basins, is 89,100 square miles, and that portion in Colorado included in the above measurement is 7,527 square miles.

The largest part of the water flowing in the Rio Grande comes from the mountains of Rio Grande and Conejos Counties, Colorado, and also, though to a less degree, from the mountains in Costilla County. The river reaches its maximum, considering all seasons of the year, at a point not far from its headwaters, for after flowing through the San Luis Park and entering New Mexico the various tributaries, though draining large areas, do not contribute a notable amount to the stream excepting in times of floods, and on the other hand there is a constant loss by evaporation and artificial diversions.

The Rio Grande Basin is a long, narrow strip of country, the perennial supply of water coming principally from a comparatively small area of about 2,000 square miles of lofty mountains. The greater part of the remaining catchment contributes water only in times of flood, that is, in the months of May and June, while during the rest of the year the waters falling within this area or coming from melting snows do not reach the trunk stream, but are evaporated or sink into the sands. In addition to the areas contributing a perennial supply of water and a spasmodic supply, there is a vast area of lost river basins from which, as mentioned before, no water comes at any time, but which from topographic features may be included within this great catchment basin.

The following descriptions of these topographic features and the character of the water supply of the subbasins embraced within the Rio Grande drainage system were taken from reports made at various times by assistants who were engaged in water measurements or preliminary examinations for reservoir sites. Among these were Messrs. L. D. Hopson, G. T. Quinby, R. S. Tarr, W. W. Follett, and H. M. Dyar. In order to condense and unify this material and combine it with data from all sources, the individual reports have not been designated, but they have been inserted as needed in geographical order.

The Rio Grande rises in southwestern Colorado (Pl. LXVIII), flows easterly for a time as a mountain stream, and finally enters the San Luis Valley about 80 miles below its source. In this valley it receives from the north the waters of the Saguache and San Luis rivers by seepage, if at all; from the west, near the lower end of the valley, the Alamosa, La Jara, Conejos, and San Antonio rivers; and from the east the Trinchera, Culebra, and Rio Costilla. About 4 miles north of the Colorado State line it enters a long canyon locally known as the Rio Grande Canyon.

The general slope of the valley is still toward the south, the river descending, however, more rapidly than does the surface of the country.

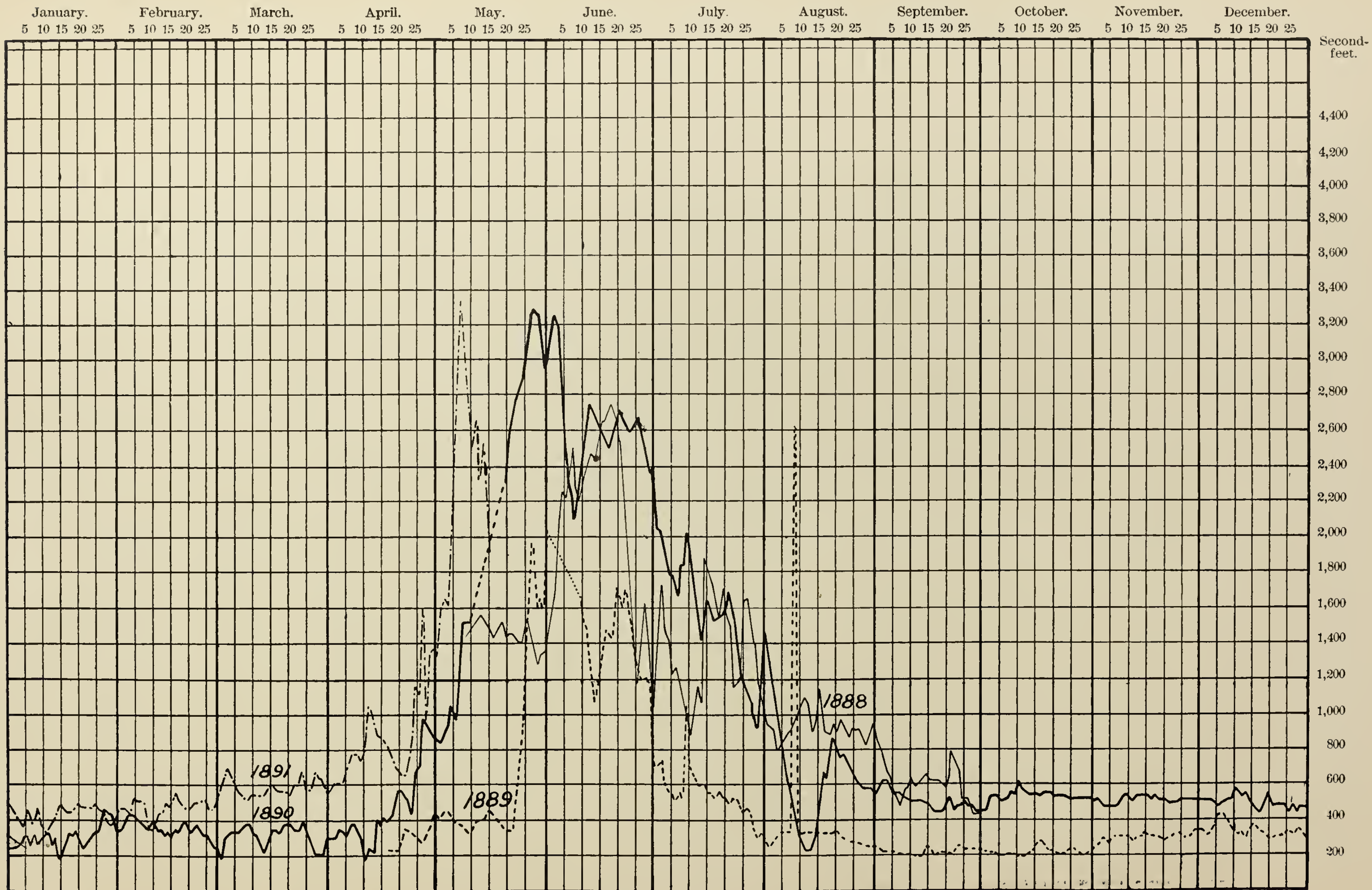
This canyon is 300 or 400 feet deep in places, appearing from above as a gash in an otherwise level mesa. Its southern end is 3 miles below Embudo, New Mexico, where the walls open and the river enters the Espanola Valley. While in the canyon above Embudo the river receives from the east Taos River, Embudo Creek, and other small streams, and in the Espanola Valley it is increased by the Chama flowing in from the west and by a number of streams from the east.

At the lower end of Espanola Valley the river passes through White Rock Canyon, a gorge in a range of hills stretching from the Jemez to the Santa Fe Mountains. From Pena Blanca near the lower end of this canyon nearly to Socorro the river flows in a valley from 1 to 3 miles wide, bounded on each side by mesas from 300 to 600 feet above the river. About 20 miles below Pena Blanca the Jemez enters from the west, and 60 miles or more below Albuquerque the Puerco comes in from the same side. Below these streams the Rio Grande has no tributaries of note until the Pecos is reached, about 400 miles by river below El Paso.

At and below Socorro the valley contracts until it becomes too narrow for agriculture, but from San Antonio to San Marcial the valley is from 1 to 2 miles wide. Below San Marcial the river swings to the westward around the Fra Cristobal and Caballos Mountains, which lie along the west edge of the Jornada del Muerto, the valley from San Marcial to Rincon being narrow, low, and marshy. At Rincon the river enters a canyon which extends to Fort Selden, a distance of 15 miles. The Mesilla Valley, the most fertile valley of New Mexico, begins below Fort Selden and extends to the pass above El Paso, a distance of over 50 miles. Above El Paso the banks of the river again assume the canyon like character for three miles, and the river passing this enters the Ysleta Valley, a fine grape and fruit producing country.

From this brief description of the river it will be seen that outside of the Mesilla Valley there are no large valleys in New Mexico along the Rio Grande or along any of its smaller tributaries, the valleys of the main river being generally narrow, seldom reaching a width of over two miles, and alternating with long canyons or gorges. The water of the stream, especially in the central and southern part of New Mexico, is heavily loaded with silt, and this is deposited to a certain extent in each of these valleys, forming broad alluvial plains. The channel of the river through these valleys is usually choked by sandbars, and in times of low water the stream divides into a number of minor channels, and apparently a large percentage of the water is lost in these great deposits of fine material.

The canyons above these valleys are not cut into hard, indurated rocks, but in many cases are bordered by steep walls of comparatively soft, friable sandstones, alternating with conglomerates or beds of clay, the whole series, in the northern part of the territory at least, being capped by a vesicular lava. The fall through these canyons being great,



DAILY DISCHARGE OF THE ARKANSAS RIVER AT CANYON CITY, COLORADO. 1888 TO 1891.

the down-cutting is rapid, and thus the waters are supplied constantly with fresh détritus, part of which is deposited in turn in the valley below.

Pl. LXIX gives a view characteristic of these canyon walls, showing the soft crumbling sandstones and the fantastic shapes into which they are carved by the rain and frost. This view was taken near the Embudo railroad station and in the vicinity of the point at which river gaugings had been made. The height of the cliffs from the bottom to the upper pinnacles shown in the picture is 500 or 600 feet, the total depth of the canyon at this point being about 1,000 feet. The sandstone crumbles readily under the hand, the only exception being in the case of a few thin bands, apparently containing a little lime, their superior hardness enabling them to resist erosion and thus stand out, as shown in the photograph. Such carvings of soft rock could, of course, exist only in an arid region, where the rainfall is too slight to erode rapidly or to encourage the growth of vegetation.

On Pl. LXVIII is given a contoured map of the basin, including on the east the drainage of the Pecos and on the southwest that of the Mimbres, although the latter river belongs to the class of lost rivers and even in times of flood does not contribute to the Rio Grande, but to the river system in Mexico west of the Rio Grande. On this map the contours show the elevation for each thousand feet above the sea, and the increase of height is further shown by the depth of tint, the highest mountains being heavily tinted. The great mountain ranges in the northern part of the basin, which furnish the principal supply of water, are thus clearly shown, and on the south the broad desert plains are seen, together with their relation to the river and to the dividing ridges of mountains. This map is of necessity generalized to a large extent, from the fact that topographic surveys have not been carried on over a large part of the area.

ANNUAL AND MONTHLY RAINFALL.

The annual rainfall, as measured in various parts of the Rio Grande basin, is shown graphically on Fig. 223, the stations selected being those in or near the basin and for which there was the longest record. Ten stations are represented on this diagram, the depth of rain at each being shown by the height of the black blocks or steps above each base line. Each year during which observations were made is represented by one of these blocks or steps, the blank spaces showing either that no observations were taken or else that they were not continuous throughout the year. The horizontal lines give the depth in inches and the vertical lines divide the five-year periods, so that wherever the observations are complete there are five of these black steps or blocks between two vertical lines. The years are shown by the figures at the top of the diagram, 1860–1864 signifying that the observations on these years whenever made are to be found in that space. Most of the obser-

vations, however, begin about 1870 and continue with more or less interruption until 1889.

This diagram serves to show the great irregularity in the measured rainfall and the range in total depth for any one place, and demonstrates how difficult it is to draw general conclusions. The most marked feature is the extraordinary rainfall reported at Fort Garland in the years 1870, 1871, and 1872. It is highly probable, however, that this report is an error, although the individual observations of the storms in these years do not seem to indicate it. In the lower left-hand corner the rainfall at two widely separated stations is given, that for Fort Selden for the years 1867 to 1876, inclusive, and that for Deming from 1883, continuing through that decade.

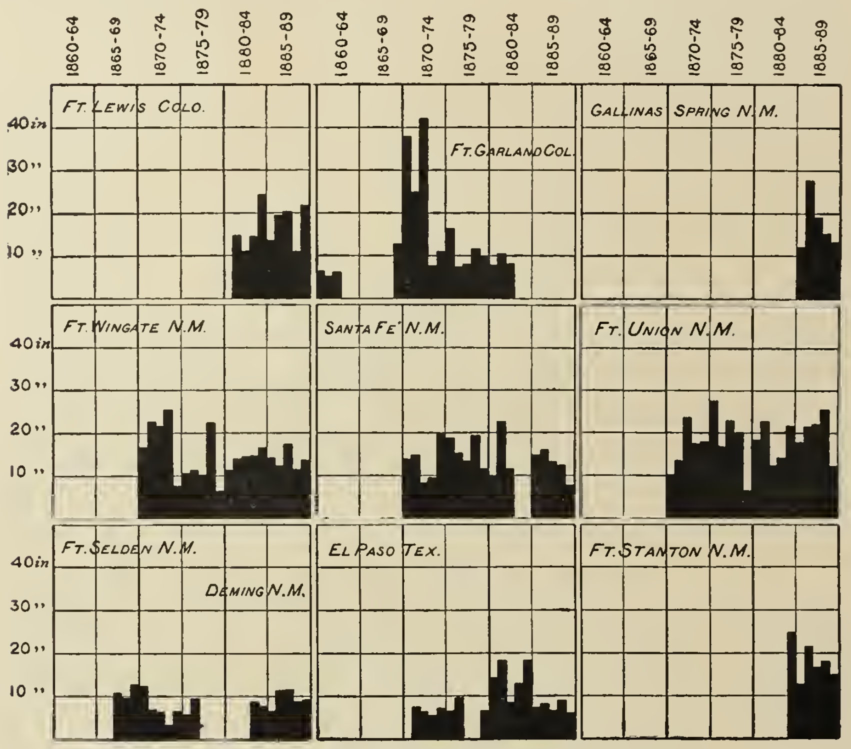
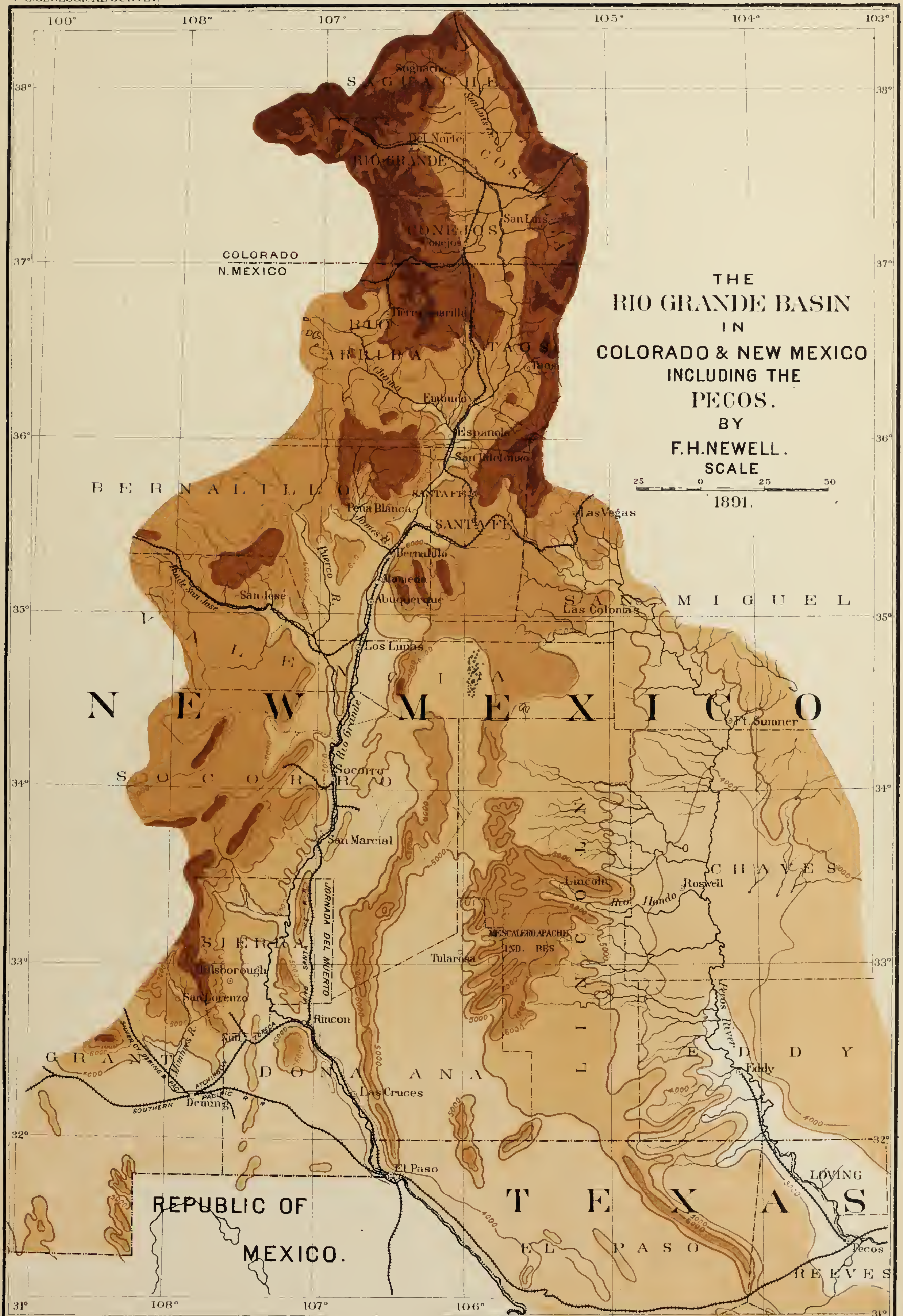


FIG. 223.—Diagram of annual rainfall in the Rio Grande Basin.

The rainfall at Fort Wingate, one of the longest of the series of measurements, shows the character of the fluctuations in this basin, in two instances years of great rainfall being immediately followed by years of drought. The Santa Fe record is broken, the years 1883 and 1884 being lost, and the El Paso record is also deficient in the years 1877 and 1878; otherwise these give a long and instructive series of observations, showing that the rainfall at most stations in the northern part of the basin seldom falls below 10 inches and rarely rises above 20. In the


THE
RIO GRANDE BASIN
IN
COLORADO & NEW MEXICO
INCLUDING THE
PECOS.
BY
F. H. NEWELL.
SCALE
25 0 25 50
1891.
COLORADO
N. MEXICO
NEW MEXICO
TEXAS
REPUBLIC OF MEXICO.
SAGUACHE
RIO GRANDE
CONEJOS
RIO ARRIBA
TAOS
BERNALILLO
SANTA FE
SAN MIGUEL
VALENCIA
SOCORRO
SIERRA
GRANT
DOÑA ANA
LINCOLN
CHAVES
EDDY
EL PASO
REEVES
LOVING
Saguache
Del Norte
San Luis
Conejos
Tierra Amarilla
Taos
Embudo
Chama
Espanola
San Ildefonso
Peña Blanca
Santa Fe
Las Vegas
Bernalillo
Alameda
Albuquerque
San José
Las Colonias
Los Lunas
Rio Grande
Puerco R.
Ft. Sumner
Socorro
San Marcial
Jornada del Muerto
Lincoln
Roswell
Rio Hondo
Mescalero Apache Ind. Res.
Tularosa
Hillsborough
San Lorenzo
Rincon
Nutt
Mimbres R.
Deming
Las Cruces
El Paso
Eddy
Pecos River
Pecos
Southern Pacific R.R.
Atchison Topeka
109° 108° 107° 105° 104° 103°
38° 37° 36° 35° 34° 33° 32° 31°
106°

southern part of the basin, however, the rainfall apparently fluctuates for the most part below 10 inches a year, at long intervals rising above this.

The distribution of the rain by months throughout the year at various stations in the Rio Grande basin is shown on Pl. LXX, the height of the small black pillars showing the mean depth of rainfall at the various stations named for a period of from 12 to 15 years. This diagram does not exhibit the rainfall in any one year, but shows the average distribution at these points. The most noticeable feature is the excessive rainfall at all stations in July, and especially in August, and the diminished amount in the early and late months of the year.

The basin of the Rio Grande can readily be divided into a number of parts, belonging to one or another of the three classes of drainage districts—headwaters, trunk-stream, or lost rivers. These are usually sharply distinguished by peculiar topographic features, and are well recognized in common usage. In the descriptions of the hydrography of these, given in the following pages, the order of succession is taken in general from the headwaters down, taking first the district in the State of Colorado, including the source of the river, the San Luis Park and the lost river basins to the north, then the Taos district and the adjoining areas, and in succession the Espanola Valley, the Chama district, the Santa Fe district, the Albuquerque Valley, the tributaries below the Chama, and the Mesilla Valley. After these descriptions of the main Rio Grande drainage, that of the Pecos in New Mexico is given, condensed from a report by R. S. Tarr, and finally the lost river basins between the Rio Grande and Pecos are briefly mentioned.

THE COLORADO DISTRICT OF THE RIO GRANDE.

The headwater district of the Rio Grande Basin, embracing the San Luis Valley, surpasses all other subdivisions in extent of irrigation and permanence of water supply, and is of the first importance in any consideration of the conservation of the waters. The general elevation of the cultivated land of this division is from 7,500 to 7,700 feet or over. The central plain is bounded by high mountains of 9,000 to over 13,000 feet in elevation on all sides, excepting on the south, where the valley opens into New Mexico. The southern boundary of this district may be taken as coincident with the State line of Colorado, for on the south the topographic features do not sharply divide this district from the adjoining portions of the Rio Grande Basin.

The great division of the river basin includes 45 square miles in San Juan County, 615 square miles in Hinsdale County, 2,520 square miles in Saguache County, 1,170 square miles in Rio Grande County, and all of Costilla County—1,720 square miles, and of Conejos County 1,200 square miles—in all an area of 7,270 square miles. The total area of the comparatively level lands of the valley is 2,400 square miles, and of the high mountains4, 870 square miles. Most, if not all, of the water must

be derived from this latter area, namely, of these higher mountains, for the rain which falls upon the valley itself does not add perceptibly to the available supply of water.

From the high mountains which surround this division come innumerable small streams, some of which unite into creeks of notable size, while others sink, gradually disappearing into the porous soil of the valley bottom. The Rio Grande rises in the extreme western prolongation of this drainage area, and flows in a general easterly course, receiving a number of these small streams on its way. Shortly after entering the valley proper, or park, as it is sometimes called, near the town of Del Norte, it begins to take a general southwesterly course, which finally changes to the south. Beyond Del Norte are few streams contributing water to the river throughout the year: so that, taking the year as a whole, the maximum amount of water in the river is to be found comparatively near the head of the river, and probably not far from Del Norte.

In its headwaters the Rio Grande is a torrential stream, but after leaving Wagon Wheel Gap it gradually loses its steep descent, and beyond Del Norte has a very light grade, becomes sinuous, and often divides into several channels, especially in floods. There is constant tendency to shift the channel and to cut off the loops, and thus great trouble and expense are occasioned to the owners of canals, in the attempt to preserve the headworks and prevent the river from washing them out or leaving them.

The gauging station of the Geological Survey is at a point about 3 miles above Del Norte, thus obtaining the discharge of the river above the headworks of most of the canals, so that the measurements given in the accompanying tables may be taken as showing the maximum flow of the river at the point between the torrential portion and the sinuous plain portion. The discharge for nearly two years is shown on Pl. LXXI, by the examination of which the relation between the floods of 1890 and 1891 can be seen at a glance. In 1891 during the early months the water was high, and there was promise of a large flood. This culminated, however, in the first week in May, and then declined rapidly, reaching its lowest point at the time when on the previous year the water was highest. The dotted line in July, August, and September gives the approximate discharge for 1889, the measured discharge for the rest of that year being shown by the fine line.

The greater portion of the catchment area of this division does not contribute water to the Rio Grande; thus there are two subdivisions—that of the perennial drainage of the Rio Grande and the lost river drainage. The entire northern or northeastern part of this division in Colorado belongs to the class of lost rivers, since the waters of the streams do not penetrate across the broad San Luis Park, but gradually disappear into the gravelly soil—as, for example, the Saguache Creek—or flow into the San Luis lakes, from which they escape by evaporation, leaving the bed dry for a part of the year.

EARTH COLUMNS AT EMBUDO, NEW MEXICO.

Although a large per cent of the drainage from the mountains surrounding the park is lost by evaporation, a small amount penetrates the soil and fills the porous strata. The extensive irrigation which is practiced in the central parts of the plain also adds water, and thus the unconsolidated sands and gravels are completely saturated. These waters gradually rising in the earth tend to create swamps, and already certain areas of valuable land have been ruined. Systems of drainage must be constructed in many places to take away this injurious excess of water.

It has been found possible to recover some of this water by means of wells, and on the lower grounds a large number of artesian wells of small diameter and of depth from 70 to 200 feet or more have been put down, giving an excellent supply for domestic purposes and for watering stock.

SAN LUIS VALLEY.

The San Luis Park or valley proper comprises the lower lands or central part of the basin, and consists of the broad extent of nearly level land, the soil being probably of lacustrine origin. Large irrigating systems take water from the Rio Grande and carry it both north and south into these rich and level bottom lands, while smaller canals and ditches owned by farmers are to be found around the edge of the valley, utilizing the water of the smaller streams.

This valley is far the largest on the Rio Grande, being nearly 70 miles long and 40 miles wide, the vast extent of unbroken land surpassing in area the total of the agricultural land along the river in New Mexico. The surface slopes from both sides away from the river, the stream flowing upon a low, broad ridge and the valley bottom as a whole falls gently toward the south, parallel to the river.

Although the altitude of the lands of the valley bottom is high, yet the climate is not too severe for agriculture. The snowfall is generally too light to insure the success of winter wheat, and disappears rapidly toward spring. The soil of the valley varies greatly, some of it being a sandy adobe, and in other places a coarse gravel. There is often a sandy loam from 8 to 15 inches thick overlying this coarse gravel. In the northwestern part of the valley, and also to a less extent throughout the park, are low swampy places known as "sinks," in which large quantities of alkali have accumulated. The adjacent land is usually a pure adobe, which, under the action of the heat, has become baked and cracked. The irrigators state that this land after cultivation becomes the easiest to till and requires the least water.

The extent of arable land is so great that the unregulated water supply is insufficient for all demands. The larger canals taking water from the Rio Grande claim many times the volume of water flowing in that stream, and have been involved in protracted and expensive lawsuits concerning their respective rights. In the same way the irrigators

owning ditches taking water from the smaller streams, having need for more water than is available at all times, are frequently involved in quarrels, and require the intervention of the water commissioners.

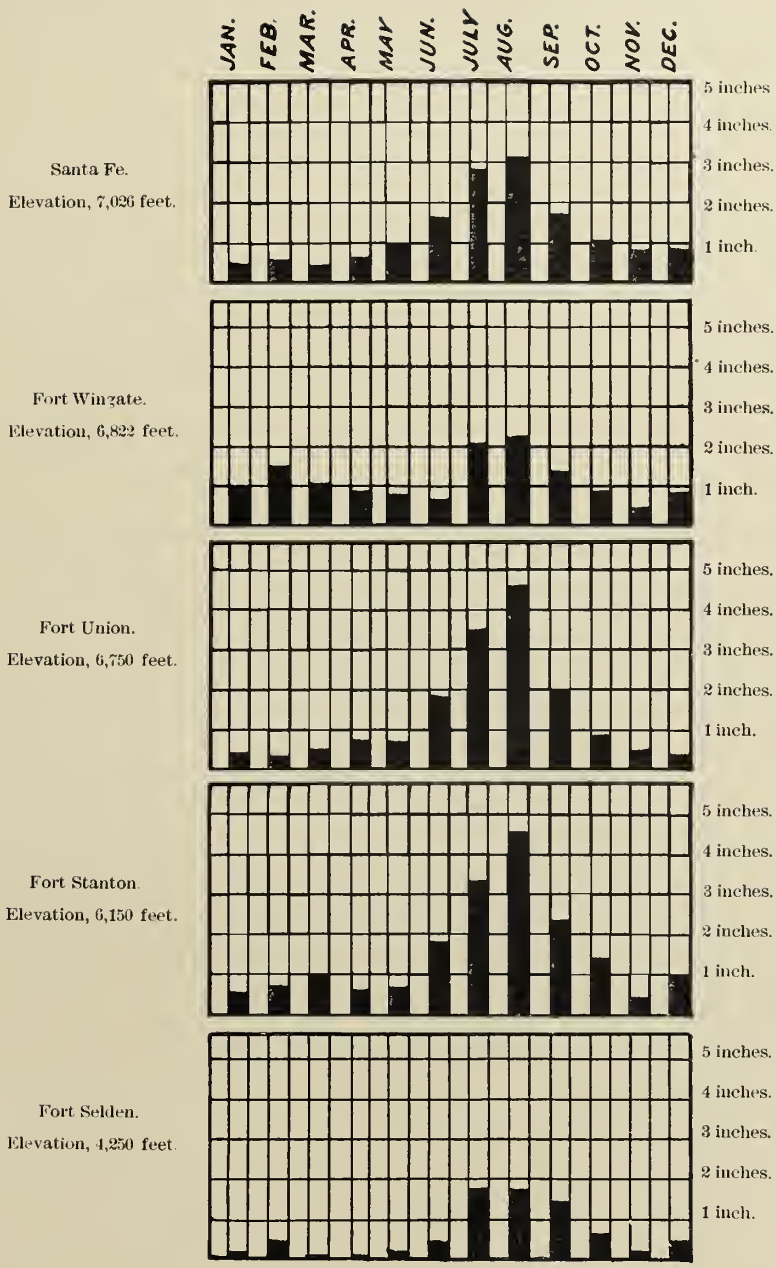
The principal crops raised are the cereals, grasses, and other forage plants. The altitude of the farming lands in the valley being so great, from 7,500 to 7,700 feet, the prevailing opinion has been that, on account of the shortness of the season, corn and similar crops would never prove successful to any extent. Alfalfa also has not succeeded in all places. Wheat, oats, barley, and the vegetables bear abundantly, and attain a growth which it is claimed, is rarely equaled in any other section of the country.

IRRIGATION PRACTICE.

The application of the water is accomplished by flooding, by running it in furrows, and by lateral seepage from the canals. For example, on one farm, rectangular in shape, the main ditch and its branch run on the west and north sides. From a point near the middle of the west side a branch of the main ditch runs diagonally to the southeast corner. Running out from the main ditch and branches at distances of from one-half to three-fourths of a mile apart are the main laterals. From these laterals at about every hundred feet the "acequias" or sub-laterals are taken out. In the case of both the laterals and acequias the general direction and number are controlled by the configuration of the ground.

If the ground is gently undulating, the acequias follow the contour, if not too sinuous, thus commanding the whole field, the irrigator alway keeping in mind the fact that the water should reach its destination in the shortest time possible with the greatest head. Small ridges several inches in height are made from the acequias to lead the water over the land. The gates having all been raised and the ditches filled, the irrigator walks along the acequia and cuts a small opening in the bank just below the ridge, allowing the water to flood the ground for some distance around. He then passes on making another opening just below, and so on throughout the field. When the ground has been flooded to a sufficient depth the openings are closed, and the water allowed to soak into the soil. The silt deposited from the turbid waters of the Rio Grande tends to enrich the ground and to prevent exhaustion of soil.

The furrow method consists simply in filling the nearly parallel furrows and allowing the water to seep laterally to the roots of the plants. The number of irrigations required to raise a crop seldom exceeds three, and is sometimes only two, depending largely upon the character of the season. Irrigation by lateral seepage from the ditches is commonly known to the farmers as subirrigation. On old land crops can be raised on the strips of ground 100 feet wide on each side of the canal, the only irrigation being the lateral seepage from the canal.



AVERAGE MONTHLY RAINFALL AT STATIONS IN THE RIO GRANDE BASIN IN NEW MEXICO.

Irrigation for grass and meadow lands begins about the 1st of May, and for grain and potatoes about a month later. After the hay is cut the ground is often given a second watering for aftermath. On meadow land three good floodings are required, except on the bottom or lowlands, where two are used. For grain there are three waterings on higher land and two on the lower land. Irrigation ends for grain and potatoes from the first to the middle of August.

In general, the larger canals in this valley are very wide and shallow, and are built for a considerable portion of their way in embankments raised slightly above the general level of the surrounding ground, allowing the water to be easily conducted out upon the fields. The loss by evaporation and seepage at such places is in consequence very great. The advantage, however, of this method of construction is that the cost of a shallow canal is usually less than of one having a deep cross section, and the banks are less liable to be destroyed. Wherever practicable, however, the canals have been partly in excavation and partly in embankment.

Almost without exception the head works of the canals, including gates, dams, flood weirs, etc., are constructed of wood, and are of a very temporary character. There are few boxes or devices employed in the valley for the absolute measurement of water, since the canal companies have not felt the necessity of accurately measuring the amount of water given to the consumer. With the increase of the number of canals and in sale of the water rights there is a prospect, however, of the general adoption of some form of measuring box or weir which measures water in statutory units.

The San Luis Valley comprises eight of the water districts of the State of Colorado, these districts being Nos. 20 to 27, inclusive. The administration of the water service of the canals lying in these districts is subject to the control of the water commissioners. The rules governing the service of the canals are enacted by the companies owning them. Many of the canals were built by irrigators, but the largest, as for example the Citizens', Del Norte, Empire, and San Luis canals, were constructed for the purpose of selling and renting water. They usually rent water for a term of from one to five years, the lessee signing an agreement binding himself to use the water for his own purposes only, not to let any of it run to waste, and to fulfill other requirements.

Some of the companies agree that whenever, through scarcity of water, due to neglect, they can not deliver the amount called for in the agreement, they will pay the damage caused thereby to the irrigator. The amount charged for the rental of water has been fixed by the companies, and generally varies from year to year. With the Citizens' and Del Norte canals the prices have ranged from 80 cents to $1 per statutory inch per year.

The farmers seem to prefer to pay a dollar or even more per statutory inch each year for the rental of water rather than buy a perpetual right

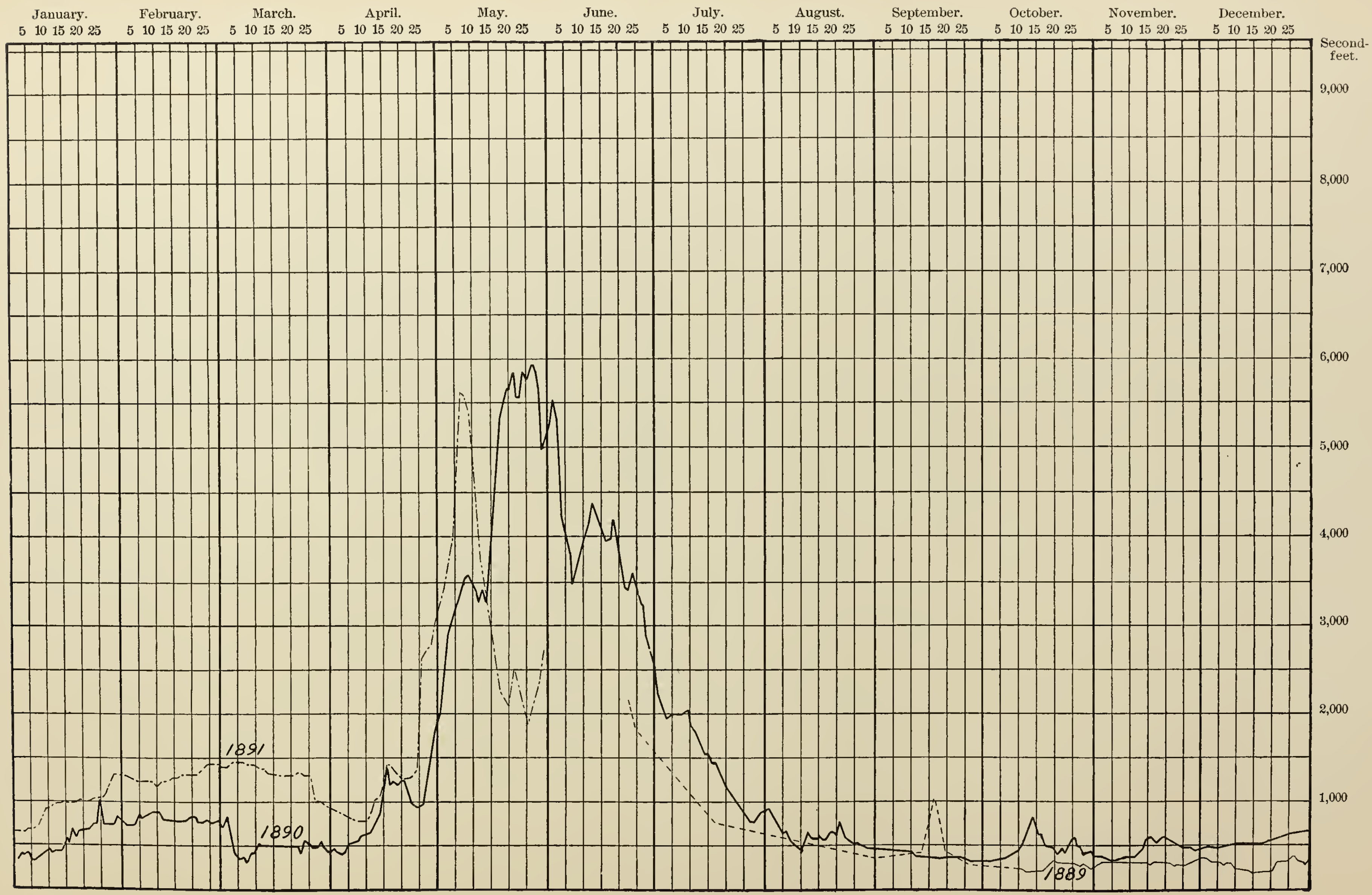
or agreement to irrigate perpetually a certain area of land. This is caused by poverty, by doubts as to the perpetuity of the right, or by fears that the company furnishing water will sell more than it is able to supply. The perpetual use of 1 inch of water has been sold for from \$5 to \$8, and in one case perpetual water rights for 160 acres sold for from \$800 to \$1,000, the rights in this case being considered to be the perpetual use of 2·88 cubic feet per second through the irrigating season. These rights are subject to an assessment each year, which the companies agree shall not exceed a specified amount, and it is further agreed by certain companies that, when three-fourths of the capacity of the canal has been sold, the management of it shall be placed in the hands of the water-users.

The duty of water in this valley has been a matter of considerable attention, but the results obtained have not been wholly satisfactory, on account of the fact that there were no devices in general use for the absolute measurement of water. In a small portion of the valley there is considered to be what is commonly known as a "standard" duty of water, viz: 1·44 cubic feet per second to 80 acres, or 1 cubic foot per second to 55·5 acres. The farmers taking water from the Del Norte and Citizens' canals buy or rent it on the basis of from ½ to 1 statute inch for each acre. This latter figure gives the extremely low duty of only 35 or 40 acres per cubic foot.

In fact, the duty of water varies very widely, on account of the differences in the character of the soil, kind of crop, the length of time the land has been irrigated, and the intelligence of the irrigator. The seepage of water through different soils is so widely different that the irrigator can not in many cases estimate what portion of the water passing through the headgate on his lateral really reaches the field. To illustrate the difference of opinion or of practice, it may be well to cite the case of a manager of one of the great farms of the valley, who asserted that certain tracts required thirteen floodings, while others required only one, or possibly two, to produce the same result.

A few farmers who have been, perhaps, more careful in the use of water, and have considered the subject thoroughly, believe that 1 statutory inch is ample for 2 acres, and state that experience has shown that 80 inches of water purchased from a canal has not only watered 160 acres, but that there has been a surplus for use on other ground. Some of the canal companies in selling water by the acre calculate at the rate of ⅝ of a miner's inch to the acre, or a duty of about 60 acres to the second-foot.

There is no doubt as to the increased duty of water from one year to another; everywhere this question, when asked, has been answered in the affirmative, and it was often stated that during the second year of cultivation the land required only about three-fourths as much water as during the first year. The duty continues to increase, but not as rapidly as at first, until the limit is reached, every portion of the ground



DAILY DISCHARGE OF THE RIO GRANDE AT DEL NORTE, COLORADO.

being thoroughly soaked. The results of this are easily observed, for in tracts of land that have been irrigated continuously for a number of years, the low portions of the field have turned into swamp. On land that has been irrigated for four years, it is asserted that on the fifth year a crop can easily be raised without any irrigation, except that from the seepage from the ditches.

THE TAOS DISTRICT OF THE RIO GRANDE.

South of the Colorado district, and immediately adjoining it, on the east side of the river, is a portion of the Rio Grande Basin, which may be called for convenience the Taos District, from the name of its principal valley. This division includes the streams flowing westerly from the group of mountains of which the Taos Range is of chief importance. The topography of this division is peculiar, and distinguishes it sharply from that of the San Luis Park to the north. The surface rocks consist largely of soft clays, sandstones, and gravels, underlaid by a broad sheet of lava, which appears on the sides of the canyons along the Rio Grande and its tributaries. These easily eroded deposits are deeply cut by occasional storms, and loose material is carried by every flood to the Rio Grande, causing its waters to be turbid and at times overloaded.

The streams leaving their mountain canyons flow for a time over this lava sheet with gentle current, depositing much of the material brought down from the heights and forming alluvial plains; then, as they approach the Rio Grande, they reach the point where the lava has been worn away, and with swift current flow rapidly downward into narrow canyons to join the main river.

The principal valleys in this division from north to south are the Cerros, Rio Colorado, San Cristobal, Arroyo Hondo, and Taos, which will be described in turn from north to south.

At Cerros there is no distinct valley or stream, but several small streams, viz, the Latir, Rito Primero, and Rito del Medio, are taken by ditches and brought into one channel, being caught just after they emerge from the Cerros Mountains. The combined flow does not exceed 20 second-feet. The amount of irrigable land is largely in excess of the present water supply, for a strip extending from the mountains to the Rio Grande, a width of some 8 miles and running parallel to the river for at least 15 miles, can easily be brought under ditch. The land to which water has been brought is scattered and irregular in outline, but there are estimated to be in all about 960 acres under ditch, and nearly all of this is farmed to a certain extent. By a proper system of storage, such as is possible on these mountain streams, the greater part of all this area might be brought under cultivation.

The first valley south of the Cerros region is that through which Colorado Creek flows. This valley is about 4 miles long and contains, it is estimated, about 1,800 acres adapted to irrigation, fully 1,500 acres of this land being under ditch; only a portion, however, is annually under

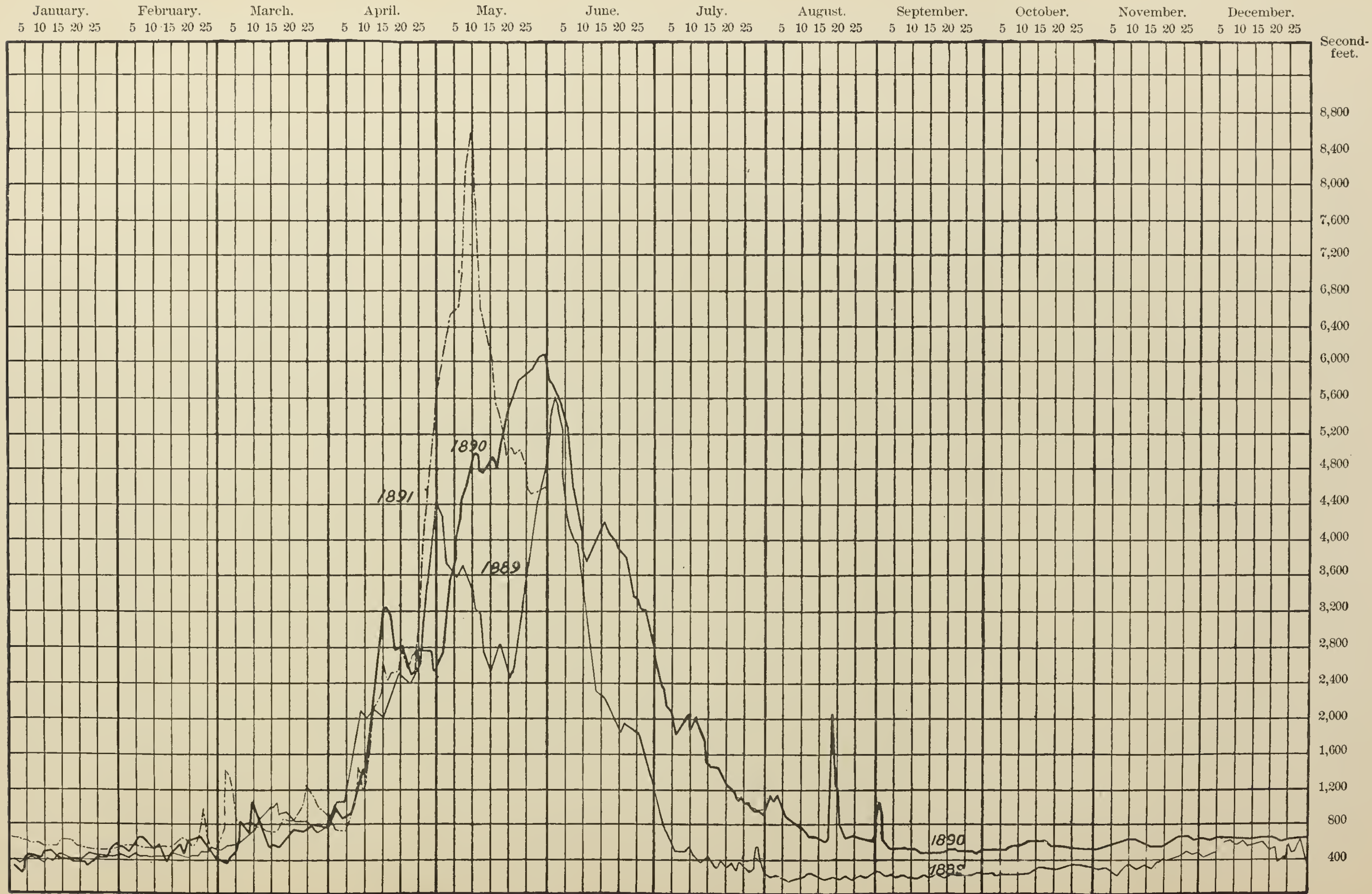
crop. The water supply is derived from two forks of the stream, which join above the place at which water is taken out. It is estimated that nearly half of the water of Colorado Creek is taken across a divide and carried to the mines at Elizabethtown. In the valley the stream was flowing at the rate of 23 second-feet early in March, 1889.

South of Colorado Creek and between it and the Arroyo Hondo is a tract of land 8 to 10 miles wide, extending from the mountains to the Rio Grande. The greater portion of this is covered with timber, heavy among the foothills but growing thinner away from the mountains. Several small creeks whose waters are used in irrigation cross this tract, the largest of these being the San Cristobal, the waters of which are used in a small valley containing about 1,800 acres of land. This is the smallest and least important of the valleys between the Rio Grande and the Taos Mountains, being occupied by a few ranches. The bench portion of the San Cristobal Valley, containing in all about 800 acres, may be considered as irrigable land; of this about 400 acres are under ditch, and the rest could be easily watered. Not more than 250 acres are actually tilled or used as hay fields. The stream is very small, and does not exceed 8 second-feet at ordinary stages, so that it is doubtful if more could be done with the present water supply.

The Arroyo Hondo is the next stream in order south of the San Cristobal. The valley through which it flows is from one-half to three-quarters of a mile wide for the distance of about 4 miles, then it contracts and again opens at short intervals. This valley is for the greater part of its course fully 500 feet below the general level of the surrounding country. The two main ditches which furnish water for the tilled land are taken out about one-half mile up in the canyon on opposite sides of the river. This stream, as measured on February 26, 1889, above these ditches, was flowing at the rate of 17 second-feet, and on November 5, 1890, at about 13 second-feet at a point below Frasier's Mill.

The land in the valley, in all from 1,200 to 1,500 acres, not including the gorge at its upper or the canyon at its lower end, may be classed as irrigable. The main ditches being taken out, one on each side, nearly all the land may be said to be under ditch. A great portion of this area is in crop, and yet it is claimed that but little over one-fourth of the total water supply is used.

South of the Arroyo Hondo is the principal valley of this division—the Taos Valley—surpassing all the others in water facilities and area of crops cultivated. The term "Taos Valley" is apt to give a false impression, for the true valley of the Taos Creek is but a shallow and rather narrow cut in the lava extending from the west side of the Rio Grande nearly to the mountains. The name is given, however, to the lava mesa, about 12 miles long from north to south and about 8 miles wide, lying between the Rio Grande and Taos Range, and having a large population, mostly Mexican. Water for irrigation is obtained



DAILY DISCHARGE OF THE RIO GRANDE AT EMBUDO, NEW MEXICO.

from Taos Creek and its branches, and from the Arroyo Hondo and Seco. The altitude, nearly 7,000 feet, is too high for many kinds of fruit, but large quantities of grain are raised.

The amount of land in the Taos Valley upon which water could be brought is very large, certainly as much as 50,000 acres, and probably even more. The most reliable information indicates about 15,000 acres actually under ditch. This acreage is difficult to estimate, as the land lies in very irregular patches, often isolated, and having an irregular frontage on a stream or ditch. On account of scarcity of water not more than one-third of the land under ditch is annually tilled, the statistics for the census year 1889 showing 5,500 acres of crops raised by irrigation.

The Taos Range to the east is well timbered with pine and spruce, and contains deposits of gold, silver, and other minerals, which are worked in a small way, development of mining industries, however, being retarded by the lack of shipping facilities.

The rainfall in the valley is estimated to be about 16 inches, the greater portion falling during August. There is no economy of water, large amounts being wasted on account of the numbers of small ditches running parallel with each other and taking the water from the river in the most wasteful manner. In place of two good high-line ditches, one on each side of the creek, so built as to carry the entire summer flow of the stream, there are several small acequias built by the early Mexican settlers in such a way as apparently to meander through the land without any system or definite order.

Three principal streams belong to the Taos Creek system, and in fact form the Taos Creek, as this name is given only to the resulting stream. Their names are Pueblo Creek, Ferdinand, and Rio Grande de Taos. From gaugings made by the hydrographers of this Survey below the junction of these creeks it appears that their winter flow does not exceed 50 second-feet. This amount is increased in the spring by melting snow, but it is doubtful if there is more water during summer irrigation, and it is even probable that at that time the supply is usually less. During the last ten years two droughts are reported to have occurred, and it is asserted that the Taos Valley for the last fifteen or twenty years has been subject to periodic droughts at intervals of about three years.

Pueblo Creek on the north enters the valley a short distance above the ancient Indian pueblo of Taos. The Indians residing here have taken out two acequias above their pueblo, one on each side of the creek. The largest ditch taken from this creek has a bottom width of 4 feet, and runs towards the town of Taos, its surplus water finally emptying into Taos Creek. Pueblo Creek carried on February 27, 1889, about 13 second-feet. Its regular summer flow is not entirely utilized.

Lucero Creek is a tributary to Pueblo Creek, coming in from the north or right-hand side, and watering the land lying between it and the Pueblo Creek, as well as a tract of land extending 2 miles to the north of the

creek. The Seco is another tributary of Pueblo Creek, its waters, however, being taken out entirely during the irrigating season, so these waters do not at that time reach Pueblo Creek. Between the Lucero and the Seco is a large tract of land that could be brought under cultivation by high-line ditches taking water from tributaries of the Arroyo Hondo, Lucero, and the Pueblo Creeks.

Ferdinand Creek issues from a narrow canyon about 3½ miles above Taos, where three or four small ditches or acequias are taken from it. The discharge of this stream on February 27, 1889, was only 3 second-feet; its summer flow was reported, however, to be considerably larger. Several years ago, during a dry season, the irrigators having land dependent upon this creek constructed a small reservoir at a favorable point several miles up the canyon, but the embankment was washed out before the end of that year.

The Rio Grande de Taos, which lies furthest to the south, has one tributary, known as the Rio Chiquito, which joins it 2 miles below the point where it enters the valley. Two small ditches are taken from this latter, while from the Rio Grande de Taos ten or more are taken out at short intervals from each other. During the summer season, when the farmers are using the water, there is little, if any, left flowing in the stream. The Rio Grande de Taos on February 23, 1889, carried 17 second-feet below its junction with the Rio Chiquito. By storage in the headwaters of this creek a large tract of land could be irrigated, an amount depending mainly upon the capacity of the reservoir.

Below Cordova the Taos River flows through a canyon to join the Rio Grande. Along its course below the town one or two acequias are taken out, but a large portion of the water is not utilized. The population of the valley is about 7,000, principally Mexicans and Pueblo Indians, these latter owning a tract of land a Spanish league square. They are peaceable and industrious, making better agriculturists apparently than their Mexican neighbors.

Wheat, corn, oats, barley, beans, potatoes, pumpkins, and other vegetables are raised in the valley, and recently apple trees have been planted with success. Alfalfa can be cut three times a year, averaging 1½ tons per acre at each cutting. The shipping facilities to and from this valley are very poor, the nearest railroad station, Embudo, being about 30 miles away.

Wheat is the most important crop grown in this valley, and flouring mills have been built at the Ranchos de Taos. Before the present railways were constructed Taos was an important flour-producing center for the surrounding towns, and even at present flour is sent by wagon or pack train to local mining camps or to be reshipped by railroad.

The Mexican system of threshing, that of treading out the wheat by goats or other animals, has led the Americans and better class of Mexicans to use other flour even when it is more expensive. An objection

to this mode of threshing is that the wheat when gathered from the ground contains pebbles about the size of the grains. It is impossible to separate these pebbles from the wheat by winnowing on account of their weight, and they are consequently ground with the wheat, making the flour somewhat gritty. Oats rank next to wheat in importance, and yield large crops. Beans and peas come next, while corn is but little grown, and then almost entirely by the Indians. Of late years the bean crop has been much damaged by the attacks of insects, amounting at times even to the loss of the crop.

Irrigation by flooding is the system practiced throughout the Taos valley. In each field, after plowing and smoothing, small banks of earth are thrown up with the plow or spade, dividing the field into a number of rectangular divisions called squares. To irrigate this land a small opening is made in the main ditch, or lateral, as the case may be, and water is allowed to flow into the first division or square, from which are openings into the next square, and so on, the water flowing from square to square over a large portion of the field.

"Banking" is but a variation of the flooding system, the water being retained as long as thought necessary in one square before it is allowed to flow into the next. The advocates of this system claim that by checking the flow in this manner the silt is deposited evenly over the whole surface, while by the former method it can be deposited only in more favorable places. The land is also more thoroughly soaked with water, and better results are therefore claimed. There is a constantly increasing use of fertilizers, such as corral scrapings and barnyard manure, and better results are obtained after their use.

Each community in New Mexico has its own customs, many of these dating as far back as the second conquest by the Spaniards. Thus, in communities often but a few miles apart, there is considerable difference in the details of water administration. Taos has the major-domo system, which prevails, with various modifications, throughout New Mexico.

Every spring one of the irrigators is elected by popular vote to the position of major-domo. His powers are wide and varied; he not only acts judicially, but he has power to see that his decisions are obeyed. The ditch is regarded as common property of all who hold land along it. In the early spring every man who takes water from the ditch meets the major-domo at the tail of the ditch and is assigned to his task by the major-domo, who measures off the sections and assigns them at random. A man is required to clean, repair, and put his section in perfect order, the major-domo alone being exempt from ditch work, but receiving no salary.

The distribution and assignment of water is entirely in the hands of the major-domo. The water is given to each irrigator for a certain period, and the decision rests entirely with the major-domo as to the length of time during which he shall have the use of the water. There

is no apparent rule as to the necessity of employing the water to best advantage, the only requirement being that no irrigator shall overrun the time allotted to him. There are complaints from both Americans and Mexicans of partiality shown by the major-domo, and it is easy to conceive into how demoralized a condition a corrupt major-domo might bring a community, especially in times of scarcity of water.

The Mexicans in the Taos Valley and the Indians are reported to have an agreement, dating as far back as the second conquest, by the terms of which the Indians were to have full and exclusive use of the water of Pueblo Creek for four days in the week. The Indians also allowed certain Mexican settlers on the Arroyo Seco to take from the Lucero, a tributary of Pueblo Creek, as much water as would flow through an old-fashioned cart or "carreta" wheel. Both of these rules are said to be observed even at the present time.

Summary of land.

Locality.	Irrigable.	Under ditch.	Cropped in 1889.
	Acres.	*Acres.*	*Acres.*
1. Cerros	100,000	960	540
2. Rio Colorado	1,800	1,500	800
3. San Cristobal	800	400	160
4. Arroyo Hondo	1,500	1,200	600
5. Taos Valley	65,000	15,000	4,000
Total	169,100	19,060	6,100

In the case of irrigable land the figures are probably much too small in the cases of Taos and Cerros. The water supply is comparatively small, and the amount of land is so vastly in excess of the available water that it is not a matter of great importance.

TRES PIEDRAS MESA.

The Tres Piedras Mesa may be taken as including all the country west of the Rio Grande and opposite the Taos Valley, extending from San Antonio Creek on the north to the Black Mesa, just above Espanola, on the south. This vast extent of practically level land is nearly all underlaid with lava. There are several townships of good land on top of the lava, but water could be brought to it only at great expense, as a ditch from the Alamosa or San Antonio River must pass through lava rock for a great part of its length. The Taos Valley Ditch Company was organized to reclaim this land, but their work is now apparently at a standstill, they having built a ditch about 40 feet wide from the Alamosa to the San Antonio, dammed the latter stream just south of Antonito, and taken out a ditch 40 feet wide from it. In May, 1889, this ditch was carrying some 500 second-feet to the end of the excavation, when the water was allowed to escape and to find its way into the Rio Grande Canyon the best it could.

EMBUDO GAUGING STATION.

In the lower end of the canyon, between the Tres Piedras Mesa and the Taos Valley, is the Embudo gauging station of the Geological Survey, located at that point for the purpose of obtaining the total discharge of the river below the Colorado divisions and above the Espanola Valley. The results of the measurements at this point are shown on the tabulations appended, and also on the diagram, Pl. LXXII. This shows a progressive increase in the amount of water from 1889 to 1891, the spring of the latter year being marked by a large flood of short duration. This flood can also be seen on the diagram, Pl. LXXI, for the Del Norte station, shown there a few days earlier and far less in amount. At Del Norte the spring flood of 1891 did not reach the maximum of the preceding year, but at Embudo it far overtops that of 1890.

Observations of the amount of sediment, as described in the previous annual reports, were carried on for a time at Embudo, and the results are shown graphically on Fig. 224, giving the observations from January 14 to April 15, 1889. In the upper part of this diagram the irregular line shows the fluctuations in the height of water, due probably to changes of temperature. The observations during January and February were made a number of times a day with great care in order to show this constant fluctuation of the height of the stream. In March and April, however, they were made only twice a day, so that the diurnal variations do not appear.

The lower part of the diagram shows the proportion of sediment in the water on those days. The dotted line connects the mean observations of samples of water taken from near the bottom of the stream, the observations themselves being shown by the small circles. The results of the sediment determinations made from samples of water taken near the surface are shown by the small crosses, the solid line connecting the mean of these whenever more than one was taken at a time. The diagram exhibits the wide range of results obtained from samples taken at the same point, at the same time, and under circumstances precisely identical. This is especially noticeable when the stream is laden with silt, check samples at that time differing greatly in the percentage of solid matter.

This lack of agreement among samples taken at times when the river is loaded with sediment is rather to be expected, from the fact that the water is moving with that peculiar boiling motion characteristic of floods, and, as can be seen by the difference in color of the water, all parts are not equally loaded. The diagram also shows that on the approach of the spring floods the proportion of sediment increases, but drops off rapidly, either by dilution or by exhaustion of the supply of fine material accumulated during periods of low water and sluggish flow.

The diagram shows the proportion of sediment by means of two scales, that of grammes per cubic foot, as given by the horizontal lines, and of

parts by weight in one hundred thousand shown by figures on each edge of the diagram. During April the proportion of sediment in the surface samples, as shown by the small crosses, increases to such an extent that this part of the diagram overlaps that showing the height of water. This diagram can be compared with that for sediment at El Paso, given on Pl. LXXIV of the last annual report. The greater amount of sediment at that latter point is shown by the fact that in the Embudo diagram the height only allows representation of 65 parts of sediment by weight in 100,000, while the smallest division of the El Paso diagram gives 100 parts in 100,000.

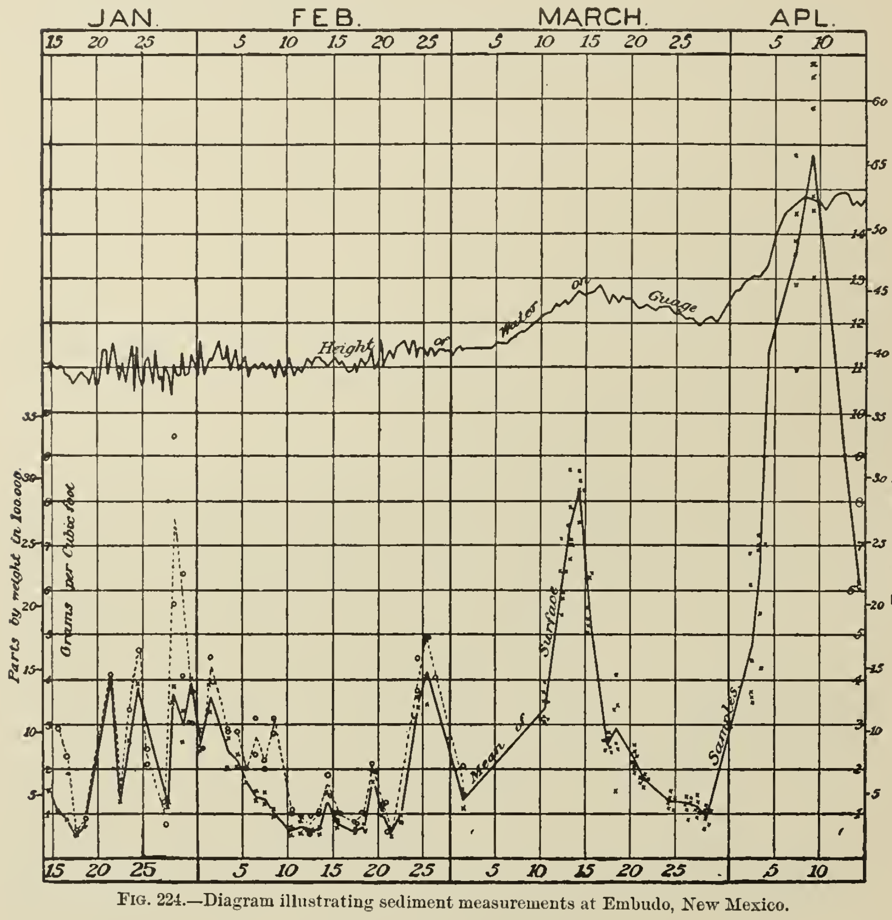


FIG. 224.—Diagram illustrating sediment measurements at Embudo, New Mexico.

ESPANOLA VALLEY.

South of the Taos district and the Tres Piedras mesa is a large valley lying along the Rio Grande and containing an area of agricultural land so great that it may be said to constitute a separate trunk-stream division of the Rio Grande system, known as the Espanola Valley. Before entering the valley the Rio Grande flows through a canyon

whose walls rise somewhat abruptly to the height of 800 to 1,000 feet. Throughout this distance the river is of a torrential character and the process of down cutting is still active. Owing to the general rocky character of the river's bed, this portion of the river is suited for the construction of headworks for a canal, which would become a high-line ditch farther down.

About three miles below Embudo Station the canyon walls retreat abruptly, especially on the west side, giving room for a border of irregular hills between the higher mesa walls and the flood plain adjacent to the river. This is the beginning of the Espanola Valley, which extends to White Rock Canyon, about 25 miles or more below. About two and one-half miles below Embudo railroad station the first acequia, of capacity of about 10 second-feet, is taken out on the east side of the river. To divert the water into it a rude dam of stones and brush has been constructed by the Mexican farmers living at La Joya.

The river assumes a different character on emerging from the canyon, the velocity being diminished and sediment deposited, forming a sandy channel and shifting banks. In this portion of the river headworks of canals can be maintained with difficulty owing to the instability of the foundations. About three-quarters of a mile below the mouth of the canyon is the Mexican village of La Joya, which stretches irregularly along the road for nearly a mile. Almost all of the low-lying land is under ditch and cultivation, as is the general rule throughout the Espanola Valley wherever the land is of good quality.

The manner of applying water to the soil is very simple. The land is laid off in squares, and the water drawn on them in most cases directly from the main ditch, though in some cases short laterals at right angles to the main ditch are used. Several thrifty orchards of apple and peach trees are to be seen at La Joya, but they were small in extent, generally not more than one-third of an acre.

From the mouth of the canyon to La Joya church there is scarcely any land that could be brought under cultivation by a high-line ditch, but below the church is a small plateau or bench, about 75 feet above the river, which might be brought under ditch, although much grading would be required in preparing the land for the water.

About 3 miles below La Joya is San Juan, an Indian pueblo, the thrift and prosperity of which, as exhibited by the fields and adobe houses, is notable. From San Juan to Espanola the lowlands are under ditch, and in the main are cultivated, but the soil appears poorer or the cultivation worse than at San Juan, and there are a few deserted houses. In the valley, as a whole, the land is irrigated only upon the lowest level, and a large tract on the east side of the river near La Joya and Alcalde, although smooth and admirably adapted for irrigation, is unused. A high-line ditch was projected, to be taken out of the river below Embudo railroad station, which was to take in this land and run as far south as the mesa beyond Santa Fe Creek. The men inter-

ested in the scheme are reputed to have obtained a small sum of money and then left without accomplishing anything in the way of construction. Not more than one-third of the irrigable land in this portion of the valley is actually under ditch.

About 5 miles above the town of Espanola the Chama River enters the Rio Grande, the muddy water brought by this stream changing the character of the river deposits. Above the junction these are sandy, but below the Chama they are of a more clayey nature and in several places the river has divided into two or more channels. Just below Espanola the Santa Cruz Creek enters the river from the east, discharging in March, 1889, about 15-second feet, but carrying a larger quantity 2 miles above Santa Cruz pueblo and the Mesilla acequia. This acequia runs about 5 miles down the Espanola Valley to and past the village of Mesilla.

Just below Mesilla are the remains of a very large ditch, which was dug about forty years ago. It extended from below Espanola to below the Huerfano Butte, a distance of from 8 to 10 miles. The owner apparently abandoned it, and the headworks were soon washed away, so that for many years there has been no water in the ditch. From the Huerfano Butte to San Ildefonso Pueblo, a distance of about three-quarters of a mile, is little or no irrigation, and no very readily irrigable land, though there are traces of old ditches, probably the end of the old ditch mentioned above.

At San Ildefonso, in the southern end of the Espanola Valley, the waters of Pojuaque Creek are used for irrigating several hundred acres, as well as for lands along this creek as far up as the village of Pojuaque. The stream was flowing about 20 second-feet when measured in March, 1889. The San Ildefonso Indians have a large body of land under cultivation between their pueblo, the river, and White Rock Canyon, all of which is served by Pojuaque water.

Only a small portion, perhaps 10 per cent, of the water of the Rio Grande is taken out in the Espanola Valley, and much of the irrigation of the valley is done with water from the creeks which flow into the river from both sides. The use of this water in preference to that of the Rio Grande is due to the greater ease with which it can be brought on the land and to the difficulty of constructing and maintaining headworks on the river.

The population of the valley is almost entirely Mexican and Indian, and, while nearly all of the easily irrigable low-lying lands are under irrigation, it is apparent that the productiveness could be much increased by better cultivation, with improved farming implements and better management. The Indians cultivate only enough land to supply their needs, and thus have large areas of fertile lands untilled. The ditches are all small and are owned and maintained by the various communities. The lands of this valley as a rule have a little alkali, but not enough to seriously interfere with agriculture. There appeared

to be a greater proportion around San Ildefonso than elsewhere, but even there it seemed to be no serious obstacle.

The eastern limit of practicable irrigation in the valley is marked by "bad lands," which consist of beds of gravel, sands, and clays, sculptured into fantastic forms by erosion similar to those shown in Pl. LXIX. The country is barren and sandy until the divide that separates the Espanola Valley proper from the Pojuaque Valley is crossed. The Pojuaque Valley is narrow, and the amount of water in the stream small, the present settlers requiring for their use all the water available. The stream flows for a great part of its course in a canyon that extends to the mountains, a few miles above Pojuaque Pueblo.

A short distance below Pojuaque the Tesuque joins the Pojuaque, the resultant stream flowing through a valley about eight miles long before reaching the Rio Grande. The Tesuque is about the same size as or a trifle smaller than the Pojuaque. The irrigable land consists of a narrow strip on each side of the stream, averaging about half a mile in width. It is doubtful if more land than at present tilled can be irrigated during dry seasons by the present unregulated supply. A high barren divide, with cedar and piñon bushes, separates the headwaters of the Tesuque from those of Santa Fe Creek to the south.

THE CHAMA DISTRICT.

The Chama,[1] which joins the Rio Grande in the Espanola Valley, is perhaps the largest tributary of that river, draining an area of 2,300 square miles, or nearly one-quarter of the total catchment area of the Rio Grande above the junction of these streams. This drainage basin consists principally of high plateaus and mountain ranges, and there are no alluvial valleys, strictly speaking, except a long, narrow valley below Abiquiu. There are, however, several low, fertile mesas, which are as valuable as valleys. The richest one is between the Nutrias and Brazos rivers, in the Tierra Amarilla grant, this tract containing also several other fine low mesas. Little, however, has been done to develop this great area, although its possibilities are large.

From Chamita, at its mouth, to Abiquiu, some 25 miles above, the Chama flows in a valley similiar to that of the Rio Grande, but with somewhat greater fall. The lower part of the river's course is through a broad valley; above this are canyons, and again a broad valley, this latter being below the canyon in the Tierra Amarilla Mountains. There are thus four general divisions, an upper and a lower valley, with a long canyon above each.

The lower Chama Valley is bordered by broken hills and bluffs of soft sandstone, similar to those shown on Pl. LXIX, clay and gravel, and the higher mesa, capped with lava, seldom approaches the river. Above Abiquiu the canyon portion, called the Canyones de Chama, commences, and extends as an almost continuous canyon to El Bado, a few miles be-

[1] Mainly from report by G. T. Quinby.

low Tierra Amarilla. There are, as is usually the case along rivers of this type, some places, locally termed "rincons," in which the valley becomes sufficiently broad for agricultural purposes. About Tierra Amarilla the third division of the river course is reached, having many of the characteristics of the lower part, the deposits in both of these divisions being probably of lacustrine origin.

The perennial tributaries of the Chama, of which there are sixteen of notable importance, vary in size from mere rills in summer to creeks whose headwaters, lying well up in the mountains, have a strong persistent flow throughout the year.

All of the tributaries entering the Chama below the Cebolla, with the exception of the Puerco or Salinas Creek, have broad sandy channels near their mouths, and thus in this portion of their course lose much water by seepage and evaporation. Their valleys are usually broad, and rise from the stream in gentle slopes on both sides, being bordered by irregular hills.

In the case of the Puerco or Salinas Creek the canyons near its mouth keep near the surface the water that would otherwise be disseminated through the sand, and on this account more water reaches the Chama. The loss of water in the Ojo Caliente, Oso, El Rito, Lower Canyones, and Cangilon is particularly large, and also, though to a somewhat less extent, in the Gallinas.

There are two general topographic features of these streams, viz: the canyon portion, in which they descend rapidly from the mountains, and the valley portion of varying width, in which they flow gently to their outlets.

On the Cebolla, Nutrias, and Nutritas the same characters exist, except that the valley portion consists of a mesa having a sheet of volcanic rock a short distance beneath the surface. The result is that a box canyon extends for a short distance from the mouth of the stream and checks in great measure the erosion above it, leaving a stream with a shallow bed flowing in a gentle depression. The Brazos, Canyones, Willow, and Little Chama belong rather to the first class of streams, those having broad valleys, but less water is lost, owing to the fact that for most of their length the sides and bottoms are formed of compact clay and the bed is narrower.

The Chama is essentially a muddy stream, and from its mouth as far up as the Gallinas Creek, not only is the Chama itself muddy, but every tributary is pouring into it a muddy torrent. Above the Gallinas the water is clearer, and its tributaries, especially the Brazos, less muddy. Taken as a whole, the Chama, however, is not so muddy as the Rio Grande south of Albuquerque, nor the Puerco below Nacimiento. The Chama and tributaries below the Cebolla carry also a considerable amount of soluble matter, and patches of alkali land are frequent. Above the Cebolla the larger streams carry but little alkali, but the smaller, particularly at low stages, apparently carry a large proportion. The alkali seems to be principally found in the lake deposits.

The amount of water in any of the streams of the Chama drainage system depends upon a wide range of modifying conditions. Most of the streams head in the mountains at an altitude of at least 8,000 feet, where the winter snowfall is usually very heavy. During the spring, while this snow is melting, the volume of the stream is swollen, and warm rains during this period are apt to produce sudden floods. After the snow has disappeared and throughout the summer occasional heavy rains cause a rapid increase in the volume of the discharge, followed by a decline almost as sudden. During the late summer and autumn the streams become low, receiving their water from the slow drainage of the ground, and remain so until the snow again melts in the spring. The increase of volume over the outflow of ground water may therefore be divided into the regular yearly increase from melting, of which an approximate estimate may be made from the amount of snow at the headwaters of the streams and the spasmodic increase from torrential rains, an adequate measurement of which can be obtained only from systematic records.

The volume of water at any point in the Chama or in any one of its tributaries depends upon two conditions: First, as has been noted, upon the weather, especially the precipitation during the season; and secondly, upon the portion of the stream at which the measurements are made—that is to say, upon the physical characteristics and structure of the valley. A great loss of water in the lower portion is characteristic not only of the Chama, but also of all of its tributaries entering below the Cebolla. This loss is occasioned by the spreading of the stream into several shallow channels in a broad sandy bed of gentle slope. The streams entering the Chama are briefly described in order upstream, the discharge of each being given as ascertained by measurements made in March and April, 1889. Oso Creek is a small stream entering the Chama from the south about 8 or 10 miles above Chamita. Its flood bed is broad and sandy, but in ordinary stages a mere thread of water flows in it. There is a brush dam near the mouth, the water being taken into the Chama Valley, as that of the Oso is very small and irregular and bordered by broken and greatly eroded hills. The discharge of the Oso March 26, 1889, was 5 second-feet.

Ojo Caliente Creek, which flows into the Chama nearly opposite Oso Creek, was measured several times and found to carry during the winter of 1888–'89 from 33 to 50 feet. The creek was higher on March 26, 1889, and was discharging about 75 second-feet.

El Rito Creek enters the Chama Valley from the north, as a small stream flowing in a flood channel nearly 200 yards in width, with banks about 8 feet in height. The valley near the mouth is narrow and the stream bed broad, but 10 or 12 miles above this point the valley widens considerably. Some 3 miles above the town of El Rito the river leaves a canyon, within which the measured discharge was found to be 33

second-feet in March, 1889. The stream at that time had evidently not acquired the full volume from the melting snow. At the same time the El Rito was flowing 9 second-feet at the point above where it empties into the Chama, the loss being probably due to evaporation and seepage.

The Frijoles is a small stream joining the Chama from the south, above Abiquiu. The bed is probably dry in summer; on March 28, 1889, however, the discharge was about 5 second-feet. The valley along this stream is of inconsiderable size.

The Canyones also enters the Chama from the south, at the lower end of a large rincon called the Vega del Riego, from a Mexican ranch in it, this point being at the upper end of the sandstone canyon above Abiquiu. The valley is sandy at its mouth, and is narrow and bordered by sandstone mesas. On March 28, 1889, the discharge was 14 second-feet, but the water was muddy, showing that the stream was somewhat swollen. In summer the bed must be dry for some distance above the outlet.

Cangilon Creek flows into the Chama from the north through a great arroyo called the Rio Seco, in passing through which a large amount of water is lost. There are openings along the course of the Cangilon containing in all several hundred acres of good bottom land. The discharge of the stream after it had emerged from Navajo canyon was found to be 28 second-feet on March 30 and 45 second-feet on April 5, 1889. The water was muddy, due to rapid melting of the snow. It is reported that the Cangilon at this point flows throughout the summer.

Gallinas Creek is a muddy stream entering the Chama from the south in a comparatively narrow, sandy valley, bordered on both sides by high sandstone mesas. The bed is sandy, and the water is spread over it in a thin sheet. Irrigation in the valley is confined to the vicinity of the town of Gallinas, some 15 or 20 miles above the mouth of the creek. The Gallinas was flowing 12 second-feet at its mouth March 29, 1889, and April 7, at Gallinas, about 20 second-feet.

Cebolla Creek enters the Chama from the east bank through a lava canyon. Above the canyon it flows through a valley, broad in comparison to the size of the stream, and with a gradual rise on each side. There is little sandy soil in the valley, but the water supply is too small to irrigate even the bottom land of the stream. With more water an enormous tract could be brought under ditch. The stream is of the type of those having clay banks, soft shale outcropping at various points in the valley, and it reaches hard rock only when it cuts through the lava sheet at its mouth. It was very muddy, flowing 12 second-feet when gauged on March 31, 1889. The discharge during summer must be very small, but it is reported that there is always some water in the channel.

Nutrias Creek also empties into the Chama from the eastern side, a few miles above the Cebolla. This valley is topographically almost identical with that of the Cebolla, and is characterized also by the great disparity between the amount of land in the valley suited for irrigation and the

small amount of water in the stream. The water of this stream was less muddy than that of the other streams above mentioned. The discharge was 10 second-feet on April 1, 1889, at the Lopez ranch, at the entrance to the canyon, below all irrigation.

The Nutritas also flows into the Chama from the east bank, a short distance above the mouth of the Nutrias and is similar to the Cebolla and Nutrias, except that this valley is somewhat narrower. Water from the Nutritas is taken out a short distance above Tierra Amarilla, and brought upon a mesa extending from that place to Park View on the Chama. There is only enough water, however, to show what might be done were it practicable in any way to increase the supply. Above Tierra Amarilla the valley rises very gradually on each side of the stream in great undulations covered by forests of long-leaf pine, none of this land being cultivated. There seems to be no surplus water in the Cebolla, Nutrias or Nutritas. The Nutritas was flowing April 1, at a point about 5 miles below Tierra Amarilla, 26 second-feet.

The Brazos is the most important tributary to the Chama, flowing into it from the east about 2 miles above Tierra Amarilla. It is formed from two streams heading high in the Tierra Amarilla Mountains, near Brazos Peak. The lower valley is broad and cultivated, but the stream flows through this in a wide, pebbly bed. From about 2 miles above its mouth to the point where it leaves the canyon it is bordered on both sides by gently rolling land covered by pine forests, which when cleared will yield valuable timber and leave several thousand acres of irrigable land. None of this pine land above Ensenada is cleared, although a couple of irrigating ditches are brought through it.

The bed of the Brazos has the bowlder-strewn character of a mountain brook, and its fall is rapid; even in stages of high water the stream is clear. On April 2, 1889, the discharge was 150 second-feet, and much of the snow in the mountains had not then melted. It is stated that the Brazos continues to discharge all summer an amount of water nearly as great as this.

The Canyones and Willow Creeks are two small streams entering the Chama from the east bank. They have very small catchment areas, and were flowing on April 4, 1889, 8 and 12 second-feet respectively. It is probable that in summer they are nearly if not quite dry. There is no cultivation in these valleys, but in places some hay is cut.

The Little Chama is the name given to the western fork of the Chama, which joins the main stream about 2½ miles below the town of Chama, flowing in a broad valley, and having steep clay banks. At the time when measured the snow was melting rapidly, and the stream was flowing bank full, and besides this, every wash and arroyo was pouring a flood of muddy water into it. It is evident, therefore, that its volume of 95 second-feet is much above the average.

Summary of water flowing in the tributaries of the Chama, as measured March 26 to April 4, 1889.

	Second-feet.
1. Oso	5
2. Ojo Caliente	75
3. El Rito	33
4. Frijoles	5
5. Canyones (Lower)	14
6. Cangilon	28
7. Puerco or Salina	40
8. Gallinas	12
9. Cebolla	12
10. Nutrias	10
11. Nutritas	26
12. Brazos	150
13. Canyones (Upper)	8
14. Willow	12
15. Little Chama	95
Total	525

This estimate does not include the water in the main branch of the Chama above the town of Chama, which must have been flowing at the rate of at least 300 second-feet. The total discharge of the Chama at Abiquiu at this time was estimated to be 750 second-feet.

Beginning at Chamita, a small Mexican town at the mouth of the river, having an altitude of 5,619 feet, the Chama Valley rises to the northward, the increase in elevation being accompanied by colder climate. At Abiquiu the altitude is 5,930 feet, but the climate is reported to be similar to that at Espanola, the Jemez Mountains to the south and rising land to the west and north affording ample shelter. From Abiquiu the land rises steadily to the west and north, and at Tierra Amarilla an altitude of 7,466 feet is reached. Here frosts occur in May, and are not uncommon even as late as the latter part of June. Much snow falls during the winter, and remains upon the ground until late in the spring. At Chama the elevation is 7,840, feet and snow usually remains upon the ground until about the first of May or even later.

Although the summer season throughout this country is short, it does not appear to have a deterrent effect upon agriculture in general, except that some of the more sensitive fruits and crops are not raised, and although the winters are colder than those of the Rio Grande Valley and the snowfall heavier, still winters as cold and snows as deep are successfully encountered by farmers in other sections of the country. There is a great compensation, however, in the increased and prolonged spring water supply.

As much as 40 per cent of the irrigable land may be considered as under ditch in the Chama Valley, not including the great area of lava mesa or the upper portion of the valley. In proportion to the amount of land in the valley suitable for irrigation the El Rito appears to have

most land under ditch, and the Vega del Riego and upper Chama, above Los Brazos, the least. In at least two cases, one above Ensenada on the Brazos, and one above Los Brazos on the Chama, a ditch ran for several miles through timbered land from which the trees had not been cleared, nor the water used on the route. Much land is also under ditch and not used on account of the peculiar location of the little isolated ranches, to water which the owner has been compelled to take water from the stream some distance above the place on which it is to be used, the intervening land thus being brought under ditch, although not owned by the irrigator.

The amount of land under crop is small, and in no instance has anything like farming on a large scale been adopted. For a large portion of the country the railways are so distant that it would appear impracticable for a farmer to attempt to raise crops larger than required for his own use, or for the limited demand of some merchant. Only in three localities is there anything approaching a general cultivation of the land. These are at Tierra Amarilla and surrounding towns, at that part of the valley between Chamita and Abiquiu, and also about the town of El Rito. In all the rest of the valley, not taking into account scattered ranches along the tributaries, the amount of irrigated land would not exceed 1,000 acres.

Summary of the estimates of irrigation.

Localities.	Irrigable.	Under ditch.	Actually under crop.
	Acres.	*Acres.*	*Acres.*
Chamita to Canyones	20,000	10,000	2,100
El Rito and Caliente	6,000	3,000	400
Vega del Riego	20,000	....	....
Smaller tributaries	10,000	4,000	600
Two Lower Terraces (La Puente to Chama)	9,000	5,000	1,300
Upper mesa (about Tierra Amarilla)	35,000	8,000	1,100
Total	100,000	30,000	5,500

These estimates are probably too small as regards the amount of irrigable land, which may prove to be nearly 50 per cent greater than is given.

In the Chama Valley as at Taos, with but few exceptions, the water is applied to the soil by flooding "squares" or small rectangles surrounded by ridges of earth, this system of taking the water directly from the main ditch and allowing it to flow from square to square being general throughout New Mexico. Apparently when the water is allowed to flow unchecked over the land, the finer sediment can be deposited only in the most favorable places, and thus quite as much soil is washed from the land as is deposited upon it.

In the case of grass, however, after the squares are full the flow is checked, and the water kept upon the ground for some time. Thus not only does the finer material have time to settle, but the soil itself

is more thoroughly soaked with water. The general opinion of the irrigators is that as now cultivated land decreases in productiveness with constant cropping. At those localities however, where this holding the water between ridges or "checks" is practiced, the decrease in productiveness is said to be less.

Wheat, oats, peas, beans, barley, corn, and potatoes are the principal crops raised in the Chama Valley. "Rust" or "smut," a parasitic growth, is one of the plagues of the wheat growers, particularly in the neighborhood of Tierra Amarilla. The "lady bug" is a source of considerable damage to the bean crop, often resulting in its partial destruction. The yield per acre of wheat is variously estimated throughout the valley, but on successful farms a little over 20 bushels per acre is probably a fair average.

Potatoes are little grown by the Mexicans, but other inhabitants find no difficulty in raising good crops. At higher altitudes, particularly near the mountains, potatoes could, without doubt, be raised without irrigation. Corn is grown only to a small extent in the upper Chama Valley, principally from the fact that it matures somewhat later in the summer than the other crops, and when water is too scanty for the final irrigation. Alfalfa is not a common crop, but more is being sown each year, and it is reported that three good crops can be cut.

Fruit and grapes are grown in the lower part of the valley and about El Rito. Some fruit is also raised about Tierra Amarilla, and there can be but little doubt that suitable varieties of apples, pears, and the more hardy fruits can be raised all through the valley.

The soil throughout the Chama Valley is in general composed of a mixture of sand and clay, the clay usually in excess. An exception may be made to this statement in the case of the lower portion of the Chama Valley, which is very sandy. The valleys of the upper tributaries, and indeed of the upper Chama itself, have a decidedly clay character, while the ridges and higher ground are usually more sandy.

The testimony appears almost entirely on the side of the opinion that when properly irrigated the land suffers no decrease in productiveness from continuous cropping. Instances are cited in which land cropped continuously for 10 or 12 years was supposed actually to have gained in productiveness. In the lower Chama Valley there is probably a large amount of silt deposited upon the land, but in the vicinity of Tierra Amarilla the streams are clearer, and a smaller amount is deposited.

So far as ascertained there is no canal company in the Chama Valley selling water. All the ditches are owned either by communities or by individuals, and no record is kept of the cost of putting water upon land. The realization that time has a money value is almost unknown among Mexicans. When they can do anything themselves, they take no account either of their time or labor. This is shown in many localities in New Mexico where brush dams, requiring yearly a great amount of labor, are common. The farming in the Chama Valley is done almost

entirely by Mexicans, the few inhabitants of other nationality being cattle men, miners and storekeepers, and on this account it has been found a matter of great difficulty to obtain reliable estimates.

Local regulations regarding the distribution of water differ in almost every town, apparently having grown up from a mixture of Spanish and Indian customs. The customs of the Pueblo Indians are essentially communal, and have left a strong impression upon the local rules now enforced, as embodied in the major-domo system, whose code is largely unwritten, but is enforced at least among the Mexicans.

In some portions of the territory water is given to the user strictly by time; in others, by the actual need of his crop for it; in others, according to the amount of land that he has under crop; and yet again, according to the amount of work he has done in repairing and clearing out the ditch. The ditch itself is built and maintained by the joint labor of the community, and is common property in the strict sense. No one is allowed to take water from the ditch unless he has either personally or by proxy done the task assigned him by the major-domo, either in the construction or in the maintenance of the ditch. As in the case of the Taos Valley, the major-domo is elected every spring, and has charge of everything connected with irrigation. In some places he is paid a small salary during the spring months; in others his services are voluntary, except that he is exempt from work on the ditch.

SANTA FE DISTRICT.

The streams of which Santa Fe Creek is the chief and which enter the Rio Grande south of the Espanola Valley can be considered as forming a division by themselves. These rise in the range east of Santa Fe and flow westerly over high plains to join the river. In the mountains at the head of Santa Fe Creek are two small lakes, which may be considered as typical of those at the head waters of other streams flowing towards the Rio Grande. Many of these can be utilized as small storage reservoirs by constructing dams at the outlets. A description of one will serve to show the conditions surrounding them.

At the head of Santa Fe Canyon is a lake about 4 acres in area, with a depth of 20 feet. Formerly this lake was larger, but some years ago an outlet was cut reducing the level by about 6 feet. This outlet can be closed by a dam and suitable gates, so that the level of the water can be raised at least 15 feet, forming a reservoir of small size, the surface area being between 5 and 6 acres in extent. In September, 1889, at the driest time of the year, a stream of about 2 second-feet was flowing from the lake.

By the utilization of this and other small reservoirs the summer flow of Santa Fe Creek can be increased, sufficiently at least to be of great benefit to the agricultural land at the time when, by reason of low water, many of the crops, and even fruit trees, are injured by drought. The elevation of these ponds is about 11,000 feet, and the evaporation is very small, since they are surrounded and protected by the mountain peaks.

Along the valley of the Santa Fe Creek, below Santa Fe, but a small amount of land is cultivated. Agriculture is limited by the small amount of water that can be depended upon during the growing season. The stream runs through a valley with gradually sloping sides as far as Cieneguilla, a Mexican town about 12 miles from Santa Fe. At Cieneguilla the stream enters the La Bajada Canyon, which is deep and narrow as far as the town of La Bajada, below which is a broader valley with a gentle slope to the left and the edge of the mesa to the right. This valley continues almost to the mouth of the creek, a distance of some 6 or 7 miles.

The mesa between La Bajada and Pena Blanca, on the Rio Grande, has a smooth surface and gentle slope, so that water could be brought from La Bajada Canyon and many thousand acres be put under ditch, if sufficient water could be obtained by storage or other means. During the spring months a large amount of water passes through the canyon, and it is probable that much water might be saved in the canyon even by dams of a temporary character, such, for example, as are used on the Puerco.

In the neighborhood of Pena Blanca the land is as thoroughly cultivated as in any part of the Rio Grande Valley. Grain fields, orchards and vineyards abound, and the ditches are carried back close around the base of conglomerate-capped sand hills that mark the edge of the valley, so that there is but little land not under ditch.

Four miles down the Rio Grande, near the mouth of the Gallisteo, the first creek south of the Santa Fe, is the pueblo of Santo Domingo, and several miles up the creek above this is the town of Wallace. A very deep ditch runs across the little divide between the Rio Grande and Gallisteo Creek, and, although the land is well adapted for irrigation, the water is not used along the ditch, but only at distant points. The Gallisteo Creek was dry when examined in January, 1889, but showed signs of frequently carrying large amounts of water, and the railway company has done considerable work to prevent it from encroaching upon their track. It drains a large watershed, and toward the headwaters a constant stream flows in the channel.

ALBUQUERQUE DISTRICT.

Under this name can be included all the Rio Grande Valley from Pena Blanca to San Marcial. The valley is narrow, being at no place over 3 miles wide, and at many points the bounding hills or mesas approach each other so closely that no room is left for bottom lands. Around Bernalillo, Albuquerque, and Belen are areas of cultivated land of excellent quality and some large vineyards; the extent, however, is not as great as in the Mesilla Valley further down the river. Below Bernalillo and also below Belen on the east side of the river are large alkali flats, once productive fields, but now worthless from lack of drainage.

The river from Pena Blanca to San Marcial occupies a broad sandy

bed, dividing in low stages into a number of narrow and crooked channels, but in flood covering in many places nearly half of the valley. Above the pueblo of San Felipe, for a distance of from 6 to 8 miles, a large percentage of the valley is under ditch. At San Felipe the valley narrows, and between the San Felipe and Algodones Creeks a large part of the agricultural land seems to have been deserted, and several of the higher ditches have been abandoned. This is possibly the effect of the Santo Domingo and San Felipe grants, which cover nine-tenths of the valley between Santo Domingo and Algodones, and are much larger than the Indians can cultivate under present conditions.

Near Bernalillo the many vineyards and orchards give to the country an appearance of prosperity. The same may be said of the valley between Bernalillo and Alameda, about half way to Albuquerque, although a large portion of the area is occupied by the broad river bed. The country about Bernalillo is one of the wine-producing centers of the valley, and is reputed to have the largest distillery in the territory.

Near Albuquerque is more waste land, and the valley is bordered by barren hills of blown sand. This sand settles in and around the low bushes of the valley, forming hillocks, which give this portion of the valley a curious appearance. Much of the land is fenced and is devoted to raising a scanty supply of a coarse grass for grazing purposes. The vineyards and orchards are smaller, and there does not seem to be the same thrift and prosperity as about Bernalillo.

From Albuquerque to Los Lunas, a distance of some 25 miles, the the western side of the valley is broader, and has great hills of wind-blown sand for its border. Only the lower and more accessible parts of the valley are irrigated, although there is a large amount of rather sandy land which is still capable of cultivation, and which could easily be brought under ditch. The valley as far below Albuquerque as Pajarito, about 8 miles, is thickly inhabited, but the average amount of land per family cultivated among the Mexicans is very small, not exceeding a couple of acres. The number of English-speaking agriculturists in the valley is insignificant.

From Albuquerque to San Marcial the drainage of the lower lands of the Rio Grande Valley is exceedingly poor. Many ponds, some of them 8 or 10 acres in extent, are full of water during the early part of the year, and others show by the alkali coating on their sides and bottoms that the water has but recently left them. This alkali coating is so universal between Los Lunas and Belen as to give to the casual observer the impression of a light snow. Apparently the Mexicans have no system either of surface or under drainage, without which it is doubtful if much further cultivation can be successfully accomplished. The ditches in this low land are liable to frequent overflow, and much damage is yearly done by their being washed out or being filled with silt.

The pueblo of Isleta, 15 miles below Albuquerque, is said to be one of the richest in the Territory, and appears to be in a more prosperous condition than the neighboring Mexican towns. Between Isleta and Los Lunas is but little farming, but at Los Lunas the vineyards are important and some wine is produced. Very little alfalfa is grown in this vicinity.

From Los Lunas south the valley is thickly inhabited, and there is a succession of small clusters of Mexican houses. The same apparent lack of industry and thrift prevails as in many places along the river bottoms, and the disadvantages of living on the low flats are shown in the number of houses which have fallen in by the sinking of the foundations. A large part of the valley south of Los Lunas is overgrown with cottonwood thickets or bosques, as they are called. Where these are cut away the land is found to be excellent. The vineyards seem to be thrifty and in good condition wherever care has been given, but the absence of orchards is notable. All along the sides of the valley, at elevations a little higher than the portions now cultivated, are lands which probably could be irrigated by higher and larger canals.

The Rio Grande Valley below La Joya station, 53 miles south of Albuquerque, narrows again, and at San Acacia the river enters a canyon about 250 yards wide, the river occupying the greater part of this width, at ordinary stages running through the sand in several channels. Below San Acacia high bluffs on the west side of the river leave only a small strip of irrigable land some 6 or 8 miles to the southward. These bluffs are farther back from the river on the east side, so that more land can be utilized, and about 5 miles north of Socorro the valley becomes considerably broader. Throughout this section, and indeed all along the valley, farming is carried on upon a petty scale, and not more than one-third of the land is under ditch. From Socorro to San Marcial the character of the valley and its conditions are essentially the same as portions already described, there being perhaps more bosques and fewer settlements. Colonies have been started just above San Marcial, and also near Fort Craig.

The methods of irrigation in this long valley are those of a past century; innumerable small ditches take water to the bottom lands only. Every town has its acequia, an unsurveyed, irregular ditch, built without method and controlled in a haphazard way. At the head are brush dams, and along the course, whenever it crosses an arroyo, the ditch is liable at every rain to be washed out, and, at nearly every road crossing, its banks are worn down by animals and wagons. The acequias are the common property of the people using them, the water tax consisting in a share of work in the ditch repairs, an amount depending upon the quantity of land irrigated. The water is supplied by the hour, a man being allowed certain days and nights in his turn, during which time he may fill his "contra acequia." The major-domo who distributes the water is supposed to see that each man gets his proper share, reckoned in hours, and that his head gate is closed at the proper time.

The results of this rather loose system are both beneficial and injurious; beneficial in that any man, even the poorest, can pay his water tax; injurious in that no one is responsible for a continuous supply of water, and because the system, once started, is seldom or never improved, and such systems are almost always begun on a very small scale.

Irrigation along the Rio Grande is in practically the same condition as when the Spaniards first passed up the valley. Some few new customs have been introduced, but the system is essentially the old Pueblo Indian system. If anything, the Indians are now in advance of the native Mexicans. Their farms are better kept, their ditches are more regular and cleaner, and their harvests are apparently more bountiful. They are more thrifty, and having a common interest they work together with less conflict than their neighbors.

There are comparatively few fruit trees or vines in this part of the valley. Occasionally an "American" ranch is passed or the farm of a wealthy Mexican, and here are almost always trees and vines in small patches. The general appearance of lack of industry in attempting permanent improvements is due, in part, to that inherent peculiarity of the natives, freedom from all thought of the future, and in part to the uncertain state of the water supply. A few acres of corn, a small patch of wheat, and a garden of chile and onions usually suffice. It would be difficult to find another valley, settled for hundreds of years, as favorable to agriculture as this, which shows so few signs of activity. The soil is capable of producing anything that will grow in a warm, temperate climate; yet in most places corn, wheat, and oats remain the staple crops.

The land in the Albuquerque Valley is for the most part excellent, portions of it, however, being subject to overflow, and other portions, as before mentioned, containing quantities of alkali. In general, it is a rich deposit of silt on the old river flood plain. Near the mesa the plain gradually passes into hummocks, layers of sand and gravel, the height of the mesa above the river varying from 15 to 50 feet, or even more. There is no doubt that the water of the Rio Grande can be led upon a part of this mesa, the soil of which is often very fertile, in places consisting of weathered basalt, although in general it is made up of water-washed gravels.

TRIBUTARIES BELOW THE CHAMA.

SANTA FE AND ADJACENT STREAMS.

In the following paragraphs a brief summary is given of the principal streams entering the Albuquerque Valley. The first of these is Santa Fe Creek, which, as previously described, discharges a very small amount of water during the greater part of the year. Gallisteo Creek flows a large amount of flood water into the Rio Grande, but often is dry for miles above its mouth, as was the case in January and February, 1889. For some 8 miles at least above its mouth it runs through

unconsolidated deposits, and in no place can anything approaching a fixed cross section be found.

A small stream comes down through Bear Canyon, in the Sandias, about east of Bernalillo, but the water all sinks within a mile or a mile and a half of the mouth of the canyon, except in times of flood. The same may be said of the stream in Tijeras Canyon, about 17 miles east of Albuquerque, except that there is an unusually good natural dam site at the mouth of this canyon. It has been proposed to make a dam at this spot, and conduct the waters held by it out upon the mesa on the east side, opposite Albuquerque.

At the mouth of the canyon are excellent facilities for erecting the dam. The stream has cut through a mass of crystalline feldspathic rock, leaving an opening not more than 150 feet wide. The rock rises abruptly in a cliff on one side to a height of 80 or 90 feet above the level of the stream. As the valley opens out to a considerable width just above the point selected for a dam, ample room is given for a large volume of water. The stream in the latter part of January, 1889, was not flowing more than 2½ to 3 second-feet, but was reported to be larger in November, when the discharge was about 4¼ second-feet, as shown by float gauging. This stream has cut back through the steep face of the Sandia Mountains, and drains a portion of the dip surface on the eastern side, thereby securing a larger drainage area than most of the small streams, and thus in flood a large amount of water is carried. The water can be brought to the surface of the mesa about 1 mile below the dam, and thence conducted over a practically indefinite amount of mesa land.

Hell Canyon, some 20 miles southeast of Albuquerque, contains a small stream, but it too sinks within a short distance of the mouth of the canyon. At Abo Paso and several points to the south are streams of the same character, but it is doubtful if there is a single stream on the east side between Pena Blanca and San Marcial that flows at the rate of 5 second-feet, except in time of flood, and in many seasons not one of them delivers any water within 10 miles of the Rio Grande.

West of the Albuquerque Valley are the large drainage areas of the Jemez and Puerco tributary to the Rio Grande. Little water flows from them during the summer. In fact, it may be said that on the west bank not a single stream below Pena Blanca, with the possible exception of the Jemez, reaches the Rio Grande, except during the annual freshets. The Salado comes in as an arroyo, about 8 miles north of Socorro. Water flows in it along the foot of Ladrones Peak, and some irrigation is done, but for the greater part of the distance it flows in a canyon.

JEMEZ RIVER.

The Jemez River enters the Rio Grande from the west at a point about 5 miles above the town of Bernalillo. It drains the country south of the Chama and west of the Santa Fe drainage. In the head-

waters are many open valleys, at an elevation of 8,000 feet and upwards, in which are hay ranches and cultivated lands. There are several localities at which water can be held by the construction of suitable dams. Leaving the mountains the small tributaries enter narrow canyons, finally uniting at the head of the Jemez Valley, about 5 miles above Jemez Pueblo.

This valley is from 1 to 3 miles in width. Its soil is in most places sandy, but with the application of water is very fertile. Agriculture is carried on to a small extent by the Jemez Indians and by the Mexicans at San Ysidro. Three miles below this latter town the Rio Salado comes in from the west through a broad, fertile valley. The valley continues to widen and contains large areas of excellent land. Small areas are cultivated by the Indians of Silla and Santa Ana, but the supply of water is deficient for their needs, or can not be diverted successfully from the river. The soil is very fertile and produces fine grapes, peaches, apples, corn, and vegetables.

In this portion of its course the river occupies a wide, sandy channel, in which the greater part of the water disappears excepting in times of flood. Below the Santa Ana Pueblo the river enters a narrow canyon, through which it continues to its junction with the Rio Grande. Throughout the lower part of its course the river is bordered by mesas covered by arable lands, to a part of which at least water could be brought from points in or near the canyons of the various tributaries.

The discharge of this river was measured at various times in 1889 and found to vary from 85 second-feet in the spring to 20 second-feet in October. This was a year of unusual drought, and the floods were very low and of short duration.

PUERCO RIVER.

South and west of the Jemez is the Puerco, a river which though draining a large area is dry at its mouth during the winter and early spring. The valley is uninhabited from the mouth as far north as the point at which the Atlantic and Pacific Railroad crosses it. The water from its principal tributary, San Jose Creek, sinks within a few miles of its mouth, although it is the largest stream in that part of the Territory, and when others were dry was flowing from Cubero to its mouth. For 40 miles up the Puerco no water could be found in February, 1889.

The divide between the Rio Grande and Puerco in its lower course, and in particular in the vicinity of Albuquerque, consists of a gently undulating mesa about 6 miles or less in width, bounded on both edges by sandy foothills. The valley at this point is about 2 miles wide, has a gentle slope, and the soil seems excellent, but very little attempt at farming has been made on account of the scarcity of water.

On the west side of the valley are deserted ranches where some irrigation has been done with the flood waters of small arroyos. It was evident from the wheat stubble and threshing floor that crops have

been raised. Considerable quantities of native hay are usually cut by the Mexicans from a broad, gentle valley known as the Canyon del Ojo. At the junction of the Canyon del Ojo with the Puerco a Mexican farmer has put in a bank about 200 feet long by 10 feet high behind which rain and flood water is caught. This he lets to a cattle owner for $200 per year.

The principal tributary of the Puerco is the San Jose, or, as known at the head waters, Bluewater Creek, which enters from the west. Below the Big Spring, near the town of San Jose, this creek was discharging from 10 to 12 second-feet in February, 1889. West of San Jose, up the creek, is a broad valley expanding toward the south. The creek bed had water in it, but usually when not swelled by melting snows it is dry at this point. Some irrigation is done by the Mexicans at the town of El Rito, about 15 miles below San Jose, but it is insignificant in amount.

About 12 miles below San Jose and between it and El Rito is the pueblo of Laguna, whose name, Lake Pueblo, is said to be derived from a former sheet of water made by an artificial dam erected by the Indians a few miles above the pueblo. This lake was probably from 130 to 160 acres in extent, and must have been from 10 to 12 feet deep in places. Nearly a quarter of the land formerly covered by the water from this lake is now occupied by crescent-shaped hills of blown sand. The dam was washed away in 1859 or 1860, and has not been rebuilt. Crops are grown in its basin, however, and a small carp pond is still preserved.

From the upper end of the San Jose Canyon clear to the head of the principal tributary, the Bluewater, along the line of the Atlantic and Pacific Railroad, is a valley at an altitude of 6,500 feet and of varying width, but of great fertility. A small portion is covered by a lava flow reaching from McCarty's west and north to Bluewater. Water for this extensive region can be had only by storage, but with this the region will become wonderfully productive. At present there are few inhabitants besides the Laguna and Acoma Indians and a settlement of Mexicans around Cubero. The San Jose, although in ordinary seasons small, must discharge an enormous quantity of flood water, for its drainage area is very great. The stream flows constantly at all seasons for some 3 miles below Laguna, where it evaporates in summer.

On the head of the Puerco, in the San Joaquin del Nacimiento grant, northwest of Jemez, is a beautiful valley covering an area some 15 miles long by 6 wide. It is so high that nothing but small grain can be raised, but the soil is extremely rich, and could a water supply be obtained, it would become a valuable tract of land. There is, however, no adequate water supply visible, and apparently this valley will long remain among the undeveloped resources of New Mexico. Farther south also are other valleys and bottom lands with little or no water for irrigation.

The Puerco holds a constant stream as far south as Casa Salazar, a point almost west of Jemez, and from there on the water is caught by

the Mexicans during the floods in brush dams. Each year brush and rocks are put in the bed of the stream and are filled with silt, forming a rough dam. The water detained in this manner is used for irrigating, but the whole arrangement is washed away in the winter and the process is repeated the next spring. This system is also used at points along the San Jose Creek. It is found to be the only one practicable, as it would be very difficult to put in a permanent dam on the clay foundations, which are over 100 feet deep, and rock does not appear anywhere near the river. As a whole, the land in the Puerco Valley seems of excellent quality, and less alkaline than the land in the Rio Grande Valley.

There is a large amount of land farther down in the Puerco Valley with a gradual slope toward the river, in all, perhaps, upward of 100 square miles. The strip is probably 70 miles long, and averages about a mile and a half in width. Little or nothing can be done with this unless a large amount of water can be stored, and in many parts of the valley there are few places favorable for the erection of dams. Even if a sufficient surplus of water could be stored near the headwaters to bring this land under ditch, still the water would have to be conveyed some 80 or 90 miles to reach the lower part of the valley, and it could be more easily brought upon one of the mesas above, where it could command a greater amount of land in a more compact form. The land throughout the Puerco Valley is of excellent quality, but the irrigation in the lower part of the valley seems to be confined to the small patches to which water held by the brush dams can be conducted.

RÉSUMÉ OF WATER SUPPLY.

To recapitulate, the principal sources of water supply above and adjoining the Albuquerque Valley are as follows: The Chama and Jemez are the only tributaries coming into the Rio Grande between Embudo and San Marcial that flow any considerable amount of water except in times of flood; the Santa Cruz, San Ildefonso, and Santa Clara, enter the Rio Grande in the Espanola Valley, but are insignificant in size; the Gallisteo and Salado discharge a considerable quantity of water in flood, but ordinarily are mere arroyos for miles from their mouth.

Between Embudo and San Marcial it has been estimated that there are about 400 square miles of irrigable land in the Rio Grande Valley. This land extends in a strip of over 200 miles in length, and will average about 2 miles in width. The White Rock Canyon, extending from San Ildefonso to Pena Blanca, and separating the Espanola and Albuquerque Valleys, is the only considerable canyon.

The methods of irrigation throughout the whole valley are very similar in character; the ditches are short, and the water is used first on the lowest levels, and gradually as more land is needed the higher levels are reached. The water is taken from the main ditch and applied directly to the highest of the small squares into which the tilled land is

divided, lateral ditches being uncommon. When this one is full, the surplus water is allowed to run into the next square below it, and so on until the lowest square is reached. Much damage is done annually to the lower ditches by the overflowing of the river and the consequent filling up or washing out of the ditches.

In short, irrigation along the Rio Grande is limited to narrow strips on either side of the stream. The valleys are narrow, and the amount of land with gentle slope suited to irrigation is comparatively small. The amount of surface water that stands in ponds through the lower part of the valley shows that in places, at least, considerable drainage is necessary, but it is doubtful if many of the native cultivators are able to make any outlay in draining and improving their land, in addition to the yearly expense for repairs to the acequias.

MESAS ALONG THE RIO GRANDE.

East of the Albuquerque Valley is a long mesa running from the Sandia Mountains on the north to Socorro on the south, and lying at an elevation of from 300 to 600 feet or more above the river. There is much fertile land on this mesa, but it lies so high that water can not be brought upon it except at enormous expense.

South of this is the Jornada del Muerto, the largest unbroken mesa in New Mexico, extending from Carthage on the north to the vicinity of Fort Selden on the south, a distance of about 100 miles. It is in places 35 miles in width, and is bounded on the east by the Sierra Oscura, San Andres, and Organ Mountains, and on the west by the smaller range of mountains bordering the Rio Grande or by the river itself. The surface is to the eye apparently level, and is covered for the greater part of the year by a grass, furnishing feed for large herds of cattle. Wells have been drilled at various points, and water struck at a depth of about 300 feet, but this is often so impregnated with salts as to be worthless.

The preliminary examinations made by this Survey show that in all probability it will be impracticable to bring water from the river upon this land, both on account of the expense and the deficiency of supply, and these level tracts with deep soil are apparently absolutely worthless for agricultural purposes. The mountains bordering the plain are low and unfitted for storing water on account of the uncertain rainfall, and the snowfall does not accumulate. Many arroyos enter the plains but none cross them, and rarely the water from a "cloud burst" in these mountains reaches the Rio Grande.

The Mesa Cuchillo Negro embraces a large extent of country west of the Rio Grande and opposite the Jornada del Muerto, lying along Rio Alamosa, Rio Cuchillo Negro, Rio Palomas, Arroyo Seco, Rio Animas, and Rio Perches. The valleys on these streams are all narrow and the bluffs high, above these being mesas containing much good land. As the fall of these streams is rapid, it may be practicable to take water out of them on to the mesas, but before this can be done a patient study

and examination of the ground must be made. The streams all head on the continental divide, and furnish a spring flow which, if stored, could be used on these mesas.

The valley bottoms lie from 300 to 500 feet below the mesas and have precipitous sides, thus making it difficult to take a ditch out of the river and carry it over the mesas. All mesa land must be irrigated, if at all, by waters stored in the upper valleys of the small streams. The development of irrigation work here, therefore, must consist in the designing of small systems of storage reservoirs and canals, work requiring much time in the examination of the country.

MESILLA VALLEY.

After leaving the Albuquerque Valley, for some miles below San Marcial, the river flows through a comparatively narrow bottom, which is not more than a quarter of a mile wide and is bordered in places by steep rocky bluffs, these disappearing farther down the river. Ten miles below San Marcial the bottom lands nearly or quite disappear, and on the left side the Fra Cristobal Mountains rise abruptly from the water's edge; while on the right or west side the ground rises gradually from the river's bank to the foothills. The river channel continues of this character to a point below the little Mexican town of San Jose where, after contracting, the valley opens again to a width of about half a mile, and abruptly contracting again the river enters a canyon.

This canyon extends for about 6 miles and varies in width from 500 to 1,500 feet at the high-water mark. The walls of the canyon are of gravel and conglomerate, overlaid by lava, which in some places, particularly on the left bank, reaches a thickness of 40 feet. The walls at the highest part are about 100 feet high, decreasing to 50 or 60 feet in places, and are cut by arroyos.

Below this gorge the river again widens, and there are patches of irrigable land at the mouths of small creeks, but the river bottom itself is narrow, and the river bed, being nearly half a mile in width, occupies nearly all of the narrow valley.

At Santa Barbara, about 10 or 12 miles above Rincon, there was formerly a large Mexican settlement in the valley, which here widens to a breadth of nearly 4 miles. The inhabitants are now gone and the village is in ruins. The probable reason is that their land became so water-soaked and saturated with alkali that they could raise nothing. By exercising a little care in drainage a few new settlers are now farming just below.

These alternations of narrow gorges and bottom lands continue nearly to Fort Selden. In this course are points at which the river bottom lands are between 5 and 6 miles in width. A very small part of this, however, is cultivated; probably there are not 100 acres of crops irrigated. There are several points at which reservoirs could be made by placing dams across constrictions in the channel. Usually, however,

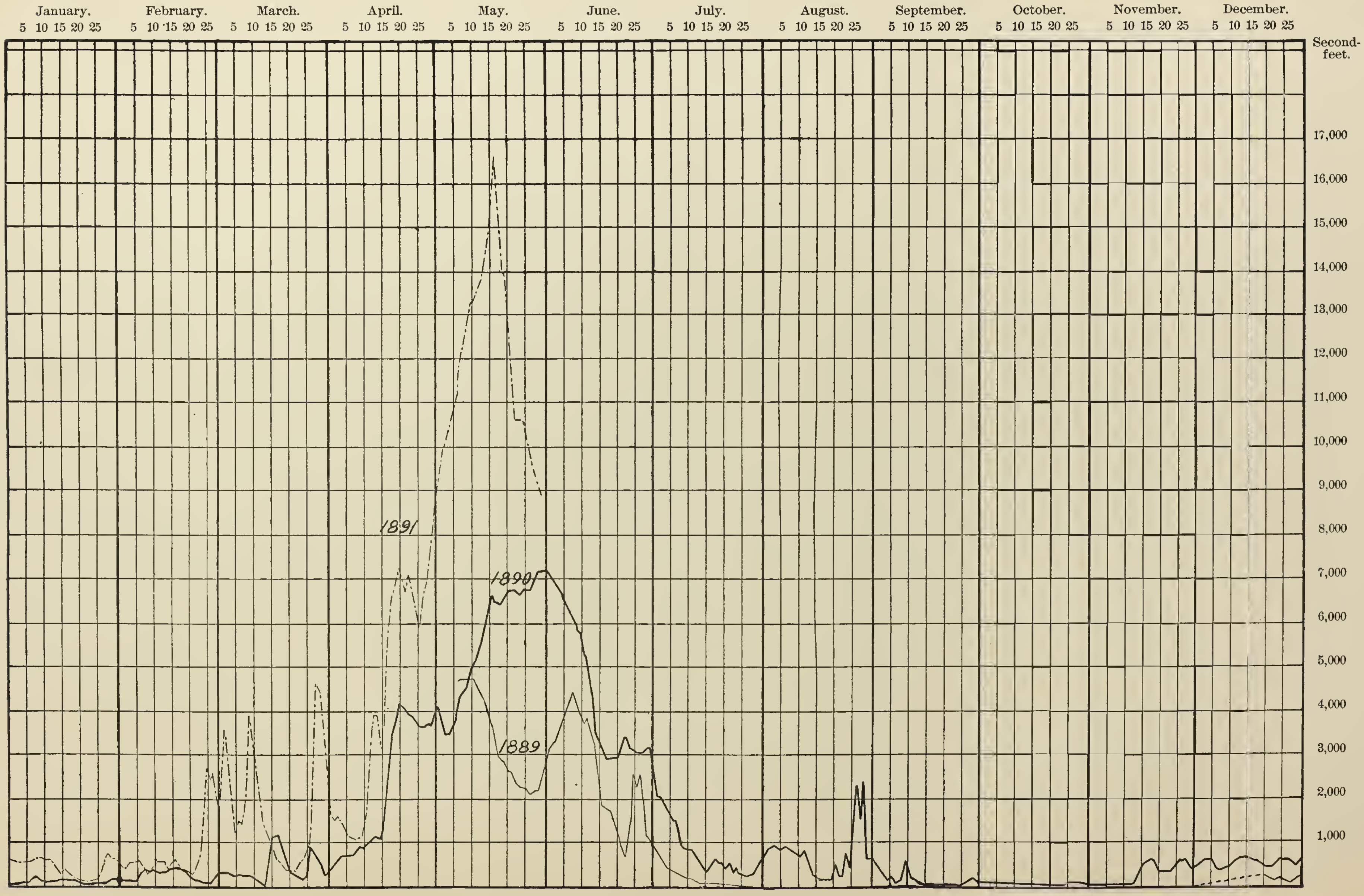
the bed of the stream is deeply filled with gravel, and it would be difficult to obtain good foundations. These reservoir sites on the main river can be utilized for storing water for the Mesilla Valley, thus allowing the summer flow of the river to be freely used on lands farther north.

Below Fort Selden the valley opens, and continues, in general, broad and fertile down to the constriction at El Paso. In this course is the Mesilla Valley, one of the best localities for fruit-growing along the Rio Grande. This valley, stretching from Fort Selden reservation on the north to the Texas line on the south, a distance of 35 miles, and with a width varying from 8 to 10 miles, includes land equal to any in the United States for the cultivation of the vine and many varieties of fruit. Below the Texas line to El Paso, 15 miles farther down the river, the soil is nearly equally as fertile, but remains almost uncultivated.

The Mesilla Valley contains probably, all things considered, the most valuable land along the Rio Grande, and the necessity of providing an ample and permanent water supply is unquestioned. The soil is of wonderful fertility and great depth, but agriculture has made slow advances, on account of the uncertainty of the future supply of water. The continued diversions along the river for hundreds of miles above this valley render the inhabitants apprehensive as to their future. At the same time that water is supplied plans must be made for drainage, for the rich bottom lands tend to become water-logged, developing the alkaline crust, as is the case in valleys below Albuquerque.

The amount of water flowing out from the Mesilla Valley for the last two years is shown graphically on Pl. LXIII, the means and extremes for each month being given in the tables appended. The gauging station is located at Fort Bliss, a short distance above the town of El Paso, the measurements being made above the Mexican dam at that place and above the head works of all ditches or canals. This diagram should be compared with that showing the discharge at Embudo, and also that for Del Norte, the similarity of these being evident at a glance. The early spring floods at El Paso are especially notable, these evidently coming from tributaries below Embudo, since they do not appear on the sheet for that station.

In briefly reviewing the use of water along the whole Rio Grande in Colorado and New Mexico, it is stated by Mr. W. W. Follett that in the San Luis Valley, besides numerous ditches, there are five large canals with a combined carrying capacity of 8,000 second-feet, although few now carry over half their maximum flow. Even then 4,000 second-feet is being used in this valley, but of course much of this water finds its way back into the river at or above the canyon. Between Embudo and San Marcial about 1,000 second-feet are used, and in the Mesilla Valley, from Rincon to El Paso, 900 second-feet are needed. At El Paso the new ditch, which owns the water rights of the old ditches on the United States side, has a capacity of about 400 second-feet, and the Mexican ditches have a capacity of about 800 second-feet.



DAILY DISCHARGE OF THE RIO GRANDE AT EL PASO, TEXAS.

Thus there is needed to supply the demand below Embudo 3,100 second-feet, as roughly estimated. Seepage will cause some water to be used many times over, but even then, except in years of maximum flow, there will be a shortage of water. Then those valleys to suffer first will be the Mesilla and the Ysleta, in which the products are worth many times as much per acre as those of the land on which the water has been used. This shows the urgent need for reservoirs. With them the Territory of New Mexico can support a much larger population in the Rio Grande Valley, but without them her progress will be slow.

GYPSUM PLAINS DISTRICT.[1]

In southern New Mexico, between the Rio Grande and Pecos, are extensive deserts, which for want of a better name may be distinguished as the Gypsum Plains. These plains are the bottom lands of a vast basin completely surrounded by hills and mountains, and extending from about White Oaks nearly to El Paso, in Texas, a distance of more than 125 miles, with a width varying from 10 to 30 miles. On the north are the Oscuro and Jicarilla Mountains and foothills; on the east the Sierra Blanca and Sacramento Mountains; on the south the Guadalupe and El Paso Mountains and foothills of the Hueco Mountains; and on the west the Organ, San Andres, and Oscuro Mountains. From each of these ranges numerous streams flow into the basin, but the water all disappears before reaching the center. Near the western margin of the plain, at the base of the San Andres range, is an extensive salt marsh, and to the south of this are the so-called White Sands, a gypsum formation.

Portions of this plain can in time become agricultural land by storing water among the higher mountains. The Sacramento, White, and Organ Mountains have a considerable depth of snow each winter and a heavy rainfall in the summer. These ranges are the only ones in this vicinity which offer opportunities for storing water.

In the center of the Gypsum Plains near the northern end is a flow of basalt, which, from all outward signs, appears to be recent, so modern in fact that there is a popular belief to the effect that it has been ejected since the Spanish invasion. At a point 15 or 20 miles north of the flow are the ruins of an ancient town; and it is reported that traces of an extensive irrigating system may still be seen near the town. At present there is no water near the place, and the canals are said to be tilted at different angles. The basalt stream is fully 30 or 35 miles in length, and has a width varying from one-quarter of a mile to 4 miles.

On the northeast of the plains is the Sierra Blanca Peak, the highest in the White Mountains, having an elevation of 11,892 feet, and wearing a cap of snow during the greater part of the year. There are numerous peaks over 8,000 feet high upon which the snowfall is very deep.

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[1] From report by R. S. Tarr, 1889.

The streams flowing from these mountains towards the west sink shortly after leaving the foothills. Among these the most important are Tularosa, Bonito, and Tres Rios. On each of these along the lower valleys farming is done by irrigation, and higher up in the mountain valleys good crops of oats, corn, and potatoes are raised without irrigation. Among the lofty peaks, deeply cut by erosión, covered with snow and drained by numerous constantly flowing streams, are probably a number of valuable reservoir sites. These will be of great utility, for to the south and southwest are the plains of almost unlimited extent at present, on account of the scarcity of water, not even grazed by cattle.

PECOS RIVER.

GENERAL TOPOGRAPHY.

The Pecos,[1] rising on the eastern side of the Santa Fe Range, flows for a while as a typical mountain stream through narrow valleys and deeply cut gorges, then leaving the tilted rocks, cuts the horizontal strata of the mesa country, this horizontal character of the rocks prevailing throughout the Pecos Valley. Among the sandstones the country is eroded and broken by arroyos, and the amount of agricultural land is necessarily small.

Below Fort Sumner, however, the topography of the valley changes. The canyon-like walls disappear, and are replaced by low rolling hills. The ascent from the river on each side becomes more and more gentle toward the south, until near Roswell there is an imperceptible gradation from the flood plain to the prairie, this change in the topography being due to change in the character of the rocks, limestone and gypsum prevailing throughout this fine agricultural land. Arroyos and gulches become rare and canyons are practically unknown, the passage from canyons to prairie land being very gradual.

The drainage of the lower Pecos in New Mexico is very imperfect, and there are broad tracts of country having no surface drainage whatsoever. The water sinks into limestone rocks, and establishes an underground drainage. The consequence of this is the formation of numerous shallow "dry lakes," which are in reality sink holes, many of these draining large areas. These contain water each year, and it is a constant surprise to the people of the country that they do not leave an alkaline crust upon disappearing, as would result if the water escaped by evaporation. East of the Pecos is the rolling prairie country of the Staked Plain, and to the west the White and other mountain chains rise out of the broken plain.

The Pecos Valley is without doubt one of the finest in New Mexico, yet it has been unknown and little developed. The reason for this is that it has been for years, and indeed until very recently, the border land of civilization. Apaches, Comanches, and Navajos had their battle

[1] From report by R. S. Tarr, 1889.

grounds here and made war upon their common enemy, the white man. Life and property were not safe, and none but the boldest of frontiersmen had the hardihood to brave the danger, the peaceful agriculturist finding no secure place.

The fine grazing land, the abundance of water, and the wildness of the life attracted only the adventurous cattlemen, who came in from Texas, Arkansas, and the surrounding territories, and developed an extensive cattle industry. Farming being considered as an interference with cattle raising, farmers were prevented even by violence from settling, and the country was held for cattle only; but by the overstocking of the ranges and the low price of cattle the owners have become so impoverished that they are in many cases forced to look to other means of self-support, and efforts are now being made to develop agricultural resources.

On the middle Pecos near the river are two classes of land—bottom land and mesa. On the lower Pecos the bottom land is also present, but the mesa is replaced by prairie. In both divisions on approaching the mountains the country becomes broken into foothills. The bottom land is irrigable, yet not one acre in a hundred has been reclaimed. It has a rich deposit of silt, uniformly level, and capable of a high state of cultivation. It is estimated that there are between 250,000 and 300,000 acres of this land lying in a narrow strip on the middle Pecos, but broadening out southward to an average width of probably 2 miles or more. A portion of it is subject to overflow, especially along the lower Pecos. In such places there is considerable alkali, though by no means as much as in similar portions on the Rio Grande.

The mesa land has a fairly good soil, in general rather thin, and composed entirely of weathered sandstone. Being high above the river and deeply cut by arroyos, it is not well placed nor suited for irrigation, and it is doubtful if any considerable portion of this upland country will be tilled. The prairie country, on account of its excellent soil, level character, and slight elevation above the river, is well suited for irrigation and offers excellent opportunities for reclamation.

CLIMATE AND WATER SUPPLY.

The climate of the Pecos Valley is typical of the arid country in which the rainfall is from 12 to 15 inches per year. In descending the valley both the elevation and the latitude become less, and there is a gradual change toward a warmer climate. The entire valley is well suited to grape culture, and at Roswell the climate is similar to that of Las Cruces on the Rio Grande. Some snow falls every winter, but in the southern portion of the valley it rapidly disappears. The rainfall comes mainly in June, July, and August, in the form of showers, and is therefore extremely variable and uncertain.

The main Pecos is formed by the confluence of the Gallinas with the Pecos at La Junta. Water flows perennially in these streams, at least

as far down as the Atchison, Topeka and Santa Fe Railroad, but between this line and La Junta the water entirely disappears by evaporation and seepage during many months of the year. On January 30, 1889, the bed of the Pecos at Las Colonias was so dry that a well 15 feet deep barely furnished a water supply for the stock and citizens of that town. A mile or two above Eden some small springs flow into the Pecos, and from this point the river channel constantly contains water. The river valley shows signs of powerful erosion, due to the floods of the spring and summer months. North of Puerto de Luna the river has a rapid slope, and is kept within its banks in time of flood, but below this point the water becomes more and more sluggish and muddy. In time of flood it overflows the flood plains extensively, but in low water meanders about among sand bars in the river bed. Above the Agua Negra Chiquita, near Santa Rosa, the water is practically free from alkali, but this stream and every one south of it add to its alkaline character.

UPPER TRIBUTARIES.

The most important tributaries of the middle Pecos, because of the constant source of supply, are the Agua Negra and Agua Negra Chiquita, entering just above Puerto de Luna. The latter on the east side of the river receives an unfailing supply of water from two large alkaline springs. The smaller rises out of the ground in a canyon about three miles from the Pecos, and carries, it is estimated, 6 second-feet. The larger spring has its source about a mile and a half from the Pecos, at the base of a low sandstone cliff on the edge of an alkaline marsh. It is remarkable for its size and depth, the basin of the spring having a diameter of about 70 feet, and a stream of water flows from it carrying about 15 second-feet, receiving additions from numerous small springs on the way through the marsh to the Pecos.

The Agua Negra flows from the Canyon Pintado, a very long arroyo on the west side of the Pecos, draining a large area of mesa country on the east side of the Manzano Mountains. During the summer rains, when great floods of water rush down the canyon, it is reported that little or none reaches the Pecos through the canyon, the greater part sinking into the arroyo bed, at one point, it is said, actually flowing into the ground through a hole. Several springs appear at various places, but they soon sink into the sand. About 3 miles from the mouth of the canyon a large and constantly flowing spring supplies a stream of water of about 7 second-feet. This may be in part the water which disappears farther up the canyon, but its constancy would seem to indicate some additional and more distant source. It is a clear alkaline water, which from its black color has been called Agua Negra by the Mexicans.

These two streams and numerous smaller springs furnish the Pecos with a considerable body of water. At Puerto de Luna the river in early Feburary is usually 150 to 200 feet wide and 2 feet deep in places,

with an average depth of one-half foot or less, and a velocity of not more than 3 feet per second. Its bed is of changing sand, and is fully 200 yards wide between the flood-plain banks, showing that powerful floods must fill the river at times when it overflows its banks. It is a treacherous stream, more difficult to control than even the Rio Grande. Near Puerto de Luna it is continually encroaching on its banks, and portions of several farms have been washed away within a few years.

Excepting occasional small springs from the Agua Negra and Arroyo Yeso, there are no living tributaries to the Pecos below Fort Sumner on the west side for a distance of 50 miles. The Yeso carries a small body of water of not more than 2 or 3 second-feet. Various arroyos, creeks, and springs of alkaline water flow into the Pecos between the Yeso and the Spring River at Roswell, but none of them are of importance, few reaching the river, and these few carrying mere threads of water.

At Roswell is the finest and most easily controlled supply of water in the territory, and an equally good body of land to be irrigated. There are five sources of water supply, the Pecos, the Hondo, the North Spring River, the Berenda, and the South Spring River. The Pecos is treacherous and difficult to control, and it is said never to fail even above the Spring River, although in summer it is often very low.

The Berenda River is one of the Spring Rivers, all of which have their source in small ponds supplied by perennial springs. The sources of all are in the midst of the prairie, within a few miles of each other and the Pecos. The Berenda, the northernmost of the three, had in February, 1889, a width of 12 feet, an average depth of $2\frac{3}{4}$ feet, and a surface velocity of 1·9 feet per second, giving approximately a discharge of 50 cubic feet per second.

The North Spring River rises in springs having a temperature somewhat higher than the average air. At 2 p. m., February 9, 1889, when the air temperature was 59° the water temperature was 67°. The union of the streams from the several springs forms the North Spring River, which had at that time a discharge of approximately 50 second-feet. Both the Berenda and the North Spring rivers empty into the Hondo before reaching the Pecos, but the South Spring River flows directly into the Pecos, the discharge being 73 second-feet.

The Hondo, formed by the confluence of numerous brooks rising in the White Mountains, flows for some distance through the foothills, and then enters the prairie country west of Roswell. Just before emptying into the Pecos it receives the water of the Berenda and North Spring rivers. In the summer above the mouth of these rivers it becomes very low and the bed even dries. In 1886 it was dry for two months; in 1887 for three weeks; in 1888 for only one. On the prairie it flows in a tortuous course through a narrow channel, cut in loose gravel, from 8 to 15 feet deep.

Float observations at Long's Ranch, 10 miles west of Roswell on the

Hondo, showed that the river on February 10, 1889, discharged 48 second-feet. Below the junction with the Spring rivers it carries about 200 second-feet at the point where a large ditch is to be taken out.

The discrepancy of 52 cubic feet per second between the measurement of the combined flow of the Hondo and its two tributaries and of the separate measurements is mainly due to the increase in size of the stream between the points where the observations were taken, due to the supply from numerous small springs. There are many of these in sight, and undoubtedly many which do not appear, and these swell the size of all the streams considerably. They are all alkaline and warmer than the air temperature, one of them being 61° and another 62°.

The entire absence of tributaries on the eastern side of the Pecos is very striking, and is due no doubt to the pervious character of the soil of the Staked Plains, upon which no drainage system is established. The only supply of water which the Pecos receives from this side comes from a few small alkaline springs or from a small arroyo which carries water once or twice in a season.

LOWER TRIBUTARIES IN NEW MEXICO.

Below Roswell the first stream of importance is the Rio Felix, which rises among the southeastern foot-hills of the White Mountains, and after a few miles sinks and does not again appear until within 4 miles of its mouth, a distance of 25 miles, where it appears again as a series of springs.

The Penasco takes its rise in the Sacramento Mountains, and formerly flowed 40 miles as a fair-sized brook, then entering a strip of marshy land 10 to 12 miles long it disappeared. There was practically no connection between the Upper and Lower Penasco, the latter commencing in a series of springs about 12 miles from the Pecos. A few years ago a cattle company cut a ditch connecting the Upper and Lower Penasco, and since then there is a continuous stream with water running 30 miles farther than formerly.

The Seven Rivers are seven small springs in the prairie, from each of which a small stream flows for a short distance, then sinks. About 35 miles below Seven Rivers is the Black River, which drains a portion of the eastern slope of the Guadalupe Mountains. It is larger than the Berenda, and carries an unfailing supply of water. This river is about 35 miles long, but is a small stream to within 16 miles of the Pecos, where its volume is considerably increased by numerous springs. It flows through a series of lakes, and is subject to extensive floods on account of the large area which it drains. A small stream, the Blue River, flows into the Black River a few miles from its mouth. The Delaware is the last stream to enter the Pecos in New Mexico, only about 7 miles being in this Territory. It is larger than the Berenda at Roswell.

From this brief description it will be seen that the constant, never-

failing supply of water in the Pecos comes from springs which must receive their supply from a great distance. This is owing to the peculiar structure of the country and the prevalence of the easily dissolved limestones, which allow the waters to make underground channels for themselves and thus flow for considerable distances out of sight. The melting snows and summer rains furnish a variable supply which fills the channels and frequently overflows the flood-plains of the Pecos and its tributaries. The river is alkaline on account of the character of the springs. No silt is received during a portion of the year from any tributaries except the Hondo and possibly the large streams south of it, yet the Pecos is muddy to an extreme, being busily employed in removing a portion of the mud brought down the arroyos in vast quantities after every rain.

AGRICULTURE ALONG THE PECOS.

The agriculturist who needs the water of the Upper Pecos River for irrigation finds himself confronted by almost insurmountable difficulties. Even the patience of the Mexican is exhausted by the freaks of this stream, and his brush dams are certainly not a success. Above Anton Chico the Mexicans succeed in irrigating small patches of land, but all their methods are crude and their results are unimportant.

Below Anton Chico all the irrigation is in the hands of Mexicans as far south as Fort Sumner. A short distance north of Anton Chico a few Mexicans succeed in raising occasional crops of oats and corn without irrigation, but farming on this plan is not a success there.

At Whitmore's ranch are the Gallinas Springs, which boil up through the clay and discharge altogether 2 or 3 second-feet, the water being used to irrigate a small farm by storing that which flows during the night to aid the supply by day. There is a large extent of valley land in this neighborhood at present uncultivated on account of the uncertain supply of water in the Gallinas River, which is frequently dry in the growing season.

From Gallinas Springs nearly to Las Colonias the river flows through a canyon with some irrigable land on either side. Above Las Colonias the canyon broadens until the walls, which are 200 to 300 feet high, are fully 2 miles apart. From the base of these cliffs on either side to the river the land is capable of irrigation, although the Mexicans have reclaimed only the narrow strip bordering the river. By the end of August the water fails in the river at this point, and there is little if any in it again until about April. On the east side some of the rich bottom lands are capable of raising a poor crop of corn without irrigation, owing, no doubt, to seepage from the river.

Below Las Colonias the canyon walls come closer together, and there is no irrigable land for 15 miles, or until Agua Negra Springs are reached. Here the valley broadens out again to a width varying from one-half mile to 2 miles or more. From this point southward the valley contracts and broadens out again at varying distances until the canyon country is left behind a few miles above Fort Sumner.

On the Pecos and Gallinas rivers north of Puerto de Luna about one-half of the easily irrigable valley land is under cultivation, but in all this region nothing has been done in the way of permanent improvement; no trees are planted, few vines, and very little alfalfa. Either the Mexicans are not thrifty, or else they are afraid to run the risk of losing trees and vines by drought and bursting of dams.

IRRIGATION WORKS ON THE PECOS.

The town of Puerto de Luna, a Mexican town, is divided into two parts by the Pecos. The western town has a very good acequia taking most of the water of the Agua Negra, and thus possesses a constant supply. All the water is utilized on small Mexican farms, each a few acres in extent. On the east side of the river many unsuccessful attempts have been made to take water out of the Pecos after the usual Mexican method, and even the Mexicans are convinced that the Pecos is entirely too changeable and violent a river for brush dams. A ditch 4 miles in length has been constructed, and four times the dam has been swept away, leaving the irrigators without water in the midst of the season. The last dam was built in the autumn of 1887, at which time a road was built to the mesa top for brush, and several thousand dollars in labor were expended in constructing the dam, which was swept away in the spring. The inhabitants are reduced to extreme poverty and are in despair. In 1888 and 1889 they were entirely without water, and, as it did not rain during the summer, those who tried to raise crops without irrigation made complete failure. The only man who had fruit trees was forced to irrigate them by carrying water in pails.

Between Puerto de Luna and Roswell little land is irrigated. Puerto de Luna is practically the limit of Mexican advance, though below there an occasional Mexican farm is found, irrigated either by a small private acequia or by spring water. At Roswell more land is cultivated, but the proportion of irrigated to irrigable land not irrigated is very small. Between Roswell and the Texas line, including the country about Roswell, there were in 1889 not more than 3,000 or 3,500 acres of land under cultivation on both sides of the river. In this tract of country there are 300,000 acres of land that can easily be reclaimed. Within a radius of from 2 to 3 miles from Roswell there were in 1889 less than 2,000 acres of cultivated land, including about 300 acres of alfalfa, 40 acres of fruit trees and vines, and 50 acres of timber planted under the timber-culture act.

The amount of cultivated land is increasing rapidly each year, and especially in the last few years there has been great activity in ditch construction. The following statements of the carrying capacity of the various acequias about Roswell in 1889 were furnished by the constructing engineer, the estimates being based upon the number of acres that each ditch could flood to a depth of 18 inches during the irrigat-

ing season, taking into account the water supply, character of the land, and size and slope of the ditch:

	Acres.
From Berenda River:	
Boon Ditch	40
Milne Ditch	100
Crow Ditch	150
From North Spring River:	
Ballard Ditch	300
Pioneer Ditch	700
Stone Ditch	1,500
Roswell Ditch	([1])
From Hondo River, Fountain Ditch	20
From South Spring River:	
East Sea Ditch	150
Corn Ditch	200
Mills Ditch	300
Poe Ditch	300
Roberts Ditch	1,500
South Sea Ditch	2,000

When all these ditches were running to their full capacity about one-half the water was taken out of the Berenda, while the amount taken

FIG. 225.—An acequia at Roswell, New Mexico.

from the North Spring River did not appear to be materially decreased, and in the South Spring River very little water was left. The Berenda at its head waters is a small stream, and possibly the carrying capacity of the first three ditches has been underestimated.

A view of one of these small ditches is given on Fig. 225, showing the general character of these acequias and the regulating gate at the head. These regulating gates, as previously stated, are of wood, roughly made, all such works being constructed by the irrigators. On

[1] Supplies the town.

the left-hand side of the picture are stacks of alfalfa, which has been raised by means of the water of the ditch. There is nothing unusual in the general appearance of this ditch, and the picture is introduced merely to show the general character of the country, since it might have been taken almost anywhere in the Rio Grande Basin.

Since 1889 several large irrigating systems have been laid out and in part completed along the Lower Pecos in New Mexico, and even extending into Texas. The most notable is that in the vicinity and south of the town of Eddy, where a masonry dam located a few miles above the town serves both to divert the water into the canals and to a certain extent to impound the floods. These canal systems have been described in great detail in various publications,[1] rendering it unnecessary at this time to enter into a description of them. The storage of surplus water is a matter of great concern to all these canal companies and irrigators, and a number of favorable reservoir sites have been surveyed and plans have been drawn up for extensive works of this character.

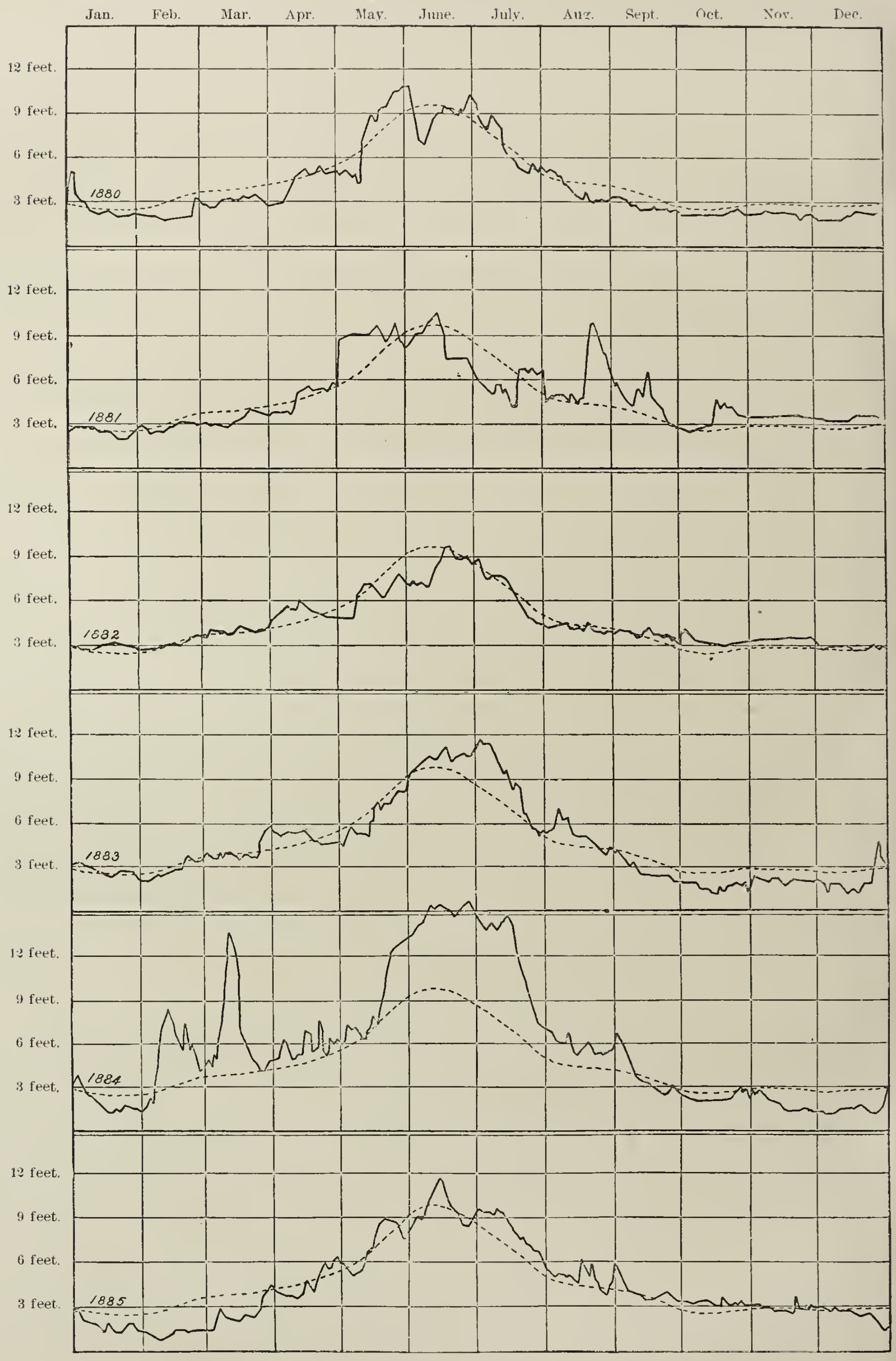
DRAINAGE BASIN OF THE COLORADO RIVER.

This great river, draining an area of 225,049 square miles and delivering a great volume of water into the Gulf of California, has within its catchment basin the most diversified and wonderful topography on the continent. The Grand and Green Rivers, rising in Colorado, Wyoming, and Utah, receive their waters from the western side of the Rocky Mountains and from the Wasatch and Uinta ranges. Uniting their floods to form the Colorado, they flow through the most stupendous canyons of the world, from 3,000 to 6,000 feet in depth below the tops of the plateaus, into which the tributary streams also have cut gigantic gorges.

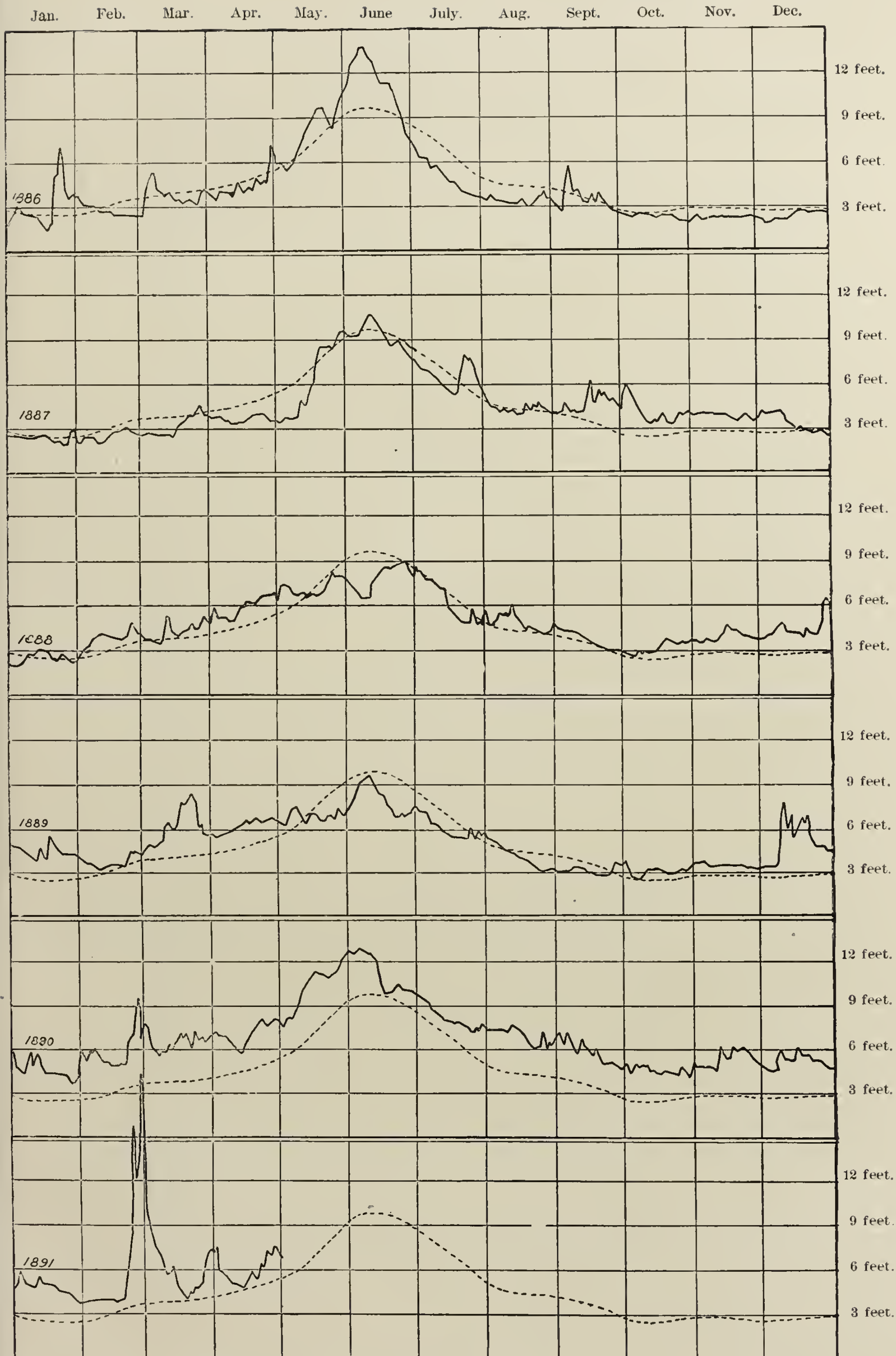
After leaving the canyons the stream meanders through the broken lands and deserts south of the Great Basin, and shortly before reaching the Gulf of California receives at Yuma the waters of the Gila River, which drains southern Arizona and a part of New Mexico, and whose basin is described in detail farther on.

On Pl. LXXIV are given the fluctuations of the river at Yuma for each year since 1880. The dotted line indicates the average height ot the river during the entire period through which measurements have been made, and the irregular line indicates the stage of water during the particular year whose date is affixed to the left side of the diagrams. An examination of these diagrams shows that in the year 1880 the height of the river was in general below the average, rising above this only for short periods and quickly falling. In 1881 and 1882 the

[1] Notably by H. M. Wilson, in the Engineering News, New York, October 17, 1891, and also in pamphlets issued by the Pecos Irrigation and Improvement Company, Eddy, New Mexico.



GAUGE HEIGHT OF THE COLORADO



…R AT YUMA, ARIZONA, 1880 TO 1891.

height followed the normal very closely, and in 1883 was for a great part of the year a trifle above.

In 1884 floods of unusual extent occurred; in March the water was higher than it had been for many years, and in the latter part of May, during June, and the first half of July the floods were unprecedented both in amount and duration. Throughout the western part of the continent this year was notable for the excessive rainfall and height of the rivers, and even in the subhumid regions the rainfall was so great that settlement was encouraged in localities where no crops have been matured since that year. By referring to the diagram of annual rainfall in the Rio Grande Basin, Fig. 223, and of that of the annual rainfall in the Gila Basin, Fig. 226, it will be seen that in nearly all the localities whose rainfall is plotted the depth of precipitation in 1884 exceeds that of the years immediately preceding or succeeding.

In 1885 the river was in general below the normal height, and in 1886 was at nearly the same stage, the June flood being larger than in the preceding year. In 1887, 1888, and 1889 the river remained at or below the normal, the June flood of the latter year being so small in comparison with that of March as barely to show an increase. In 1890 the water remained above the normal for the whole year, but the June flood, which promised to be so large, dropped off abruptly in the middle of the month.

The spring of 1891 was characterized by the greatest flood of which a record has been kept. This came, as have most of those of February and March, from the Gila Basin, where a large amount of damage was done by the extraordinary rains. This sudden flood is interesting from the fact that it was probably the cause of the submergence of a portion of the Colorado Desert in the central part of San Diego County, California. The lowest part of this desert, at a point about 60 miles west of the Colorado River, is 225 feet or more below sea level. The Southern Pacific Railroad runs through this depression, and the unexpected appearance of the water at this remote point occasioned some alarm and also damage to the salt works on the lowest ground.

Discharge measurements of the Colorado River were made by the Wheeler Survey in 1875 and 1876 at three points—Stone's Ferry in Nevada, below the mouth of the Virgin, at Camp Mohave, Arizona, and at Fort Yuma, California, the results of which are given in a memorandum by Lieut. Bergland.[1]

At Stone's Ferry the measurements on August 12, 1875, gave the area of section as 5,723 square feet, width 480 feet, mean velocity 3·217 feet per second, and discharge 18,410 second-feet. The high-water mark of 1871 was 17·01 feet above surface of water at the time of observations. Increase of area at high water was 9,773 square feet. The

[1] Annual report upon the geographical surveys west of the 100th meridian in California, Nevada, Utah, Colorado, Wyoming, New Mexico, Arizona, and Montana, by George M. Wheeler, first lieutenant of engineers, U. S. A., being Appendix JJ of the annual report of the Chief of Engineers for 1876, pp. 71-72, 119-125, Washington, 1876.

whole discharge at that time takes place through the section. Assuming the mean velocity to remain the same as on August 12, 1875, the increase in discharge would be 31,440 second-feet; but as in reality there would also be an increase in the velocity, the increase in discharge would be somewhat greater than this.

At Camp Mohave on September 2, 1875, the area of section was 4,628 square feet, width 1,116 feet, mean velocity 2·508 feet per second, and discharge 11,611 second-feet. The high-water mark of 1874 was 8 feet above surface of river on that date. The increase of area of section at high water, excluding overflow on flats, would be 13,656 square feet, and the increase in discharge through the section would be 34,274 second-feet, but as a considerable quantity of the bottom beyond the section is then covered with water, this will not represent the total increase.

At Fort Yuma on March 20, 1876, the area was 2,726 square feet, width 461 feet, mean velocity 2·809 feet per second, and discharge 7,659 second-feet. The high-water mark of 1862 was 10·19 feet above the surface of the river. The increase of area of section at high water would be 5,059 square feet. The increase in discharges through section would be 14,244 second-feet. Here the velocity throughout the section would be increased at time of high water, and a large quantity would flow outside of the section, since the bottom lands would be flooded.

Adding the increase of discharge, due to the increase of area, to that measured, the flood discharges at the three places would be at least 49,850, 45,885, and 21,903 second-feet, respectively, to which is to be added the amount passing outside the sections, which in the case of Fort Yuma is large. It is stated that the computed increase for Camp Mohave is probably nearer the truth than that for the other localities.

THE GILA BASIN.

TOPOGRAPHY AND ALTITUDES.

The Gila Basin (Pl. LXXV), the most southerly portion of the great Colorado drainage basin, includes the greater part of Arizona, as well as a portion of New Mexico and of Sonora, in the Republic of Mexico. In all this area of 66,020 square miles the success of agriculture depends upon the artificial application of water to the crops. This water is derived from the Gila River and its tributaries by means of canals and ditches, which distribute it to the fields of each farmer. These streams fluctuate greatly, being at times subject to sudden floods, especially during summer rains, when they often sweep out bridges, dams, and canal head works, while at other times they may diminish until the water almost disappears. In floods there is, of course, far more water than can be used, although at this season as much as possible is put upon the crops, especially the forage plants, and great quantities are turned upon the fields in order to saturate the ground; but, on the other hand, during the ordinary low stages of the streams, the acreage of crops is limited to that which can be watered by the diminished flow.


THE
GILA BASIN.
BY
F.H.NEWELL.
Scale.
25 0 25 50 75 100 MILES.
PRESCOTT
Wickenburg
Seymour
Hassayampa
Agua Fria
Phoenix
SALT RIVER IND.RES.
Arizona Dam
Globe
WHITE MT. IND. RES.
GILA RIVER IND. RES.
GILA BEND IND. RES.
Maricopa
Florence
Buttes
Casa Grande
Texas Hill
Gila River
YUMA IND.RES.
Yuma
SOUTHERN PACIFIC R.R.
Dudleyville
San Pedro
Camp Thomas
Gila
Clifton
San Francisco R.
Solomonsville
Camp Grant
Camp Lowell
TUCSON
Camp Bowie
PAPAGO IND.RES.
Santa Cruz R.
Tombstone
Charleston
Silver Cr.
Y A V A P A I
M A R I C O P A
A R I Z O N A
P I N A L
G R A H A M
P I M A
C O C H I S E
M E X I C O
GULF OF CALIFORNIA

On Pl. LXXV is given a map of the basin on a scale of 40 miles to the inch, with contour interval of 1,000 feet. This is taken from the U. S. Geological Survey map of 1891 and shows in a general way, as is necessary on this scale, the elevations in this basin. It has been derived from all material accessible and gives at a glance the present condition of our knowledge of this important region.

By glancing at this map it will be seen that the high land of the basin, as indicated by the darker color, is along the northeastern edge. By consulting the full map from which this is taken it would be seen that this rim of the basin is not composed of high mountain ranges, as might appear from the small map alone, but is really the edge of a great plateau. Against the edge of this great plateau the prevailing winds from the south or southwest strike, and, being forced upward, as they rise deposit their moisture in the form of rain or snow, which, rolling backward, forms the small streams that, uniting, feed the Gila.

The map shows these little streams flowing in a general southwesterly direction and in the northern part of the basin uniting to form the Verde, which flows southerly parallel to the face of the cliffs. A little farther to the south and east these streams unite in the Salt, which also flows very nearly parallel to the edge of the drainage basin, but to the west to meet the Verde. On the extreme eastern edge of the basin the plateau-like character gives place to mountain ranges, and a less regular arrangement of the small tributaries is found there. They flow in almost every direction, to unite finally in the Gila, which takes a course nearly parallel to that of the Salt.

The remainder of the rim of the basin is poorly defined. The elevations are lower, and consequently the precipitation is less, and, with little rainfall, the streams are small, and seldom extend sufficiently far from the mountains to unite into a perennial river. Most of them sink into the broad, sandy plains soon after leaving their canyons; and while from the considerations of the topography they may be considered as belonging in the drainage basin of the Gila, yet they seldom or never contribute to its waters.

Thus the drainage basin of the Gila may be considered as consisting of two great divisions—that on the northeast, shown on the map by the heavy tints, rugged and precipitous, catching the moisture from the clouds; and that to the southwest consisting principally of vast areas of nearly level land, shown in lighter tint, much of it exceedingly fertile, and in every way adapted to agriculture, excepting in the one particular, the lack of water. Were it not for the position of these high plateaus, all of this fertile land would remain forever valueless to the farmer, and thus it is that the mountain region, even if it were of no other use, would still be valuable as a collector of rainfall. This great area, however, is not wholly useless, for much of it is valuable mineral land, the mines from which have brought prosperity to parts of the basin.

Assuming that this map of the drainage basin is approximately correct, sufficiently so for general purposes, computations have been made of the area of land lying at different elevations, the results being as follows: The total area of the basin is 66,020 square miles. Of this area—

9 per cent is under 1,000 feet.
19 per cent is between 1,000 and 2,000 feet.
16 per cent is between 2,000 and 3,000 feet.
14 per cent is between 3,000 and 4,000 feet.
15 per cent is between 4,000 and 5,000 feet.
12 per cent is between 5,000 and 6,000 feet.
8 per cent is between 6,000 and 7,000 feet.
7 per cent is over 7,000 feet.

The greater portion of the land lying at an elevation of less than 3,000 feet, may be classed as sandy plains, in large part agricultural if water could be supplied; in other words, about 44 per cent of the entire area of the basin would fall into this class. The lands over 5,000 feet in elevation may be considered as mountainous catchment areas. These aggregate 27 per cent of the entire basin, and it is from this 27 per cent, or a portion thereof at least, that all of the water comes.

The greater part, if not all, of the grazing and mining regions are included within this 27 per cent, as well as all the timber. The land from 3,000 to 5,000 feet above the sea is partly plain and partly foothill. A small part is agricultural, especially at the headwaters of the Verde and those of the Upper Gila, but in the main it is broken country, of little value even for grazing.

In this connection it is important to note the political divisions which have been made in the drainage basin, for much of their prosperity depends upon the wisdom and foresight with which the boundaries of States and counties have been laid out. This is particularly the case in the arid regions, where the one thing of value is the water, and where the land takes its value only from its position as regards the water supply. If the boundaries of States and counties had been made to coincide with natural divisions, so that the streams with their headwaters would lie in one grand division, the future control and management of the water would be comparatively simple; but in the cases (which are unfortunately too common) where, for example, the headwaters of a stream are in one State and the irrigable land in another, there is constant strife, or even an abandonment of great natural resources.

The Gila basin includes, besides the greater part of southern Arizona, a small portion of the Territory of New Mexico, and the State of Sonora, in the Republic of Mexico. In the case of this latter country the rim of the basin has been arbitrarily assumed, as there are no available maps which define it, and on the southwestern edge the boundary between the United States and Mexico is taken as the limit of the basin. This area, by counties, is shown in the following table:

	Square miles.	
Socorro County, New Mexico	3,893	
Sierra County, New Mexico	156	
Grant County, New Mexico	2,818	6,867
Republic of Mexico		1,168
Apache County, Arizona	2,550	
Graham County, Arizona	6,152	
Cochise County, Arizona	6,004	
Gila County, Arizona	3,212	
Pinal County, Arizona	5,300	
Pima County, Arizona	10,596	
Yavapai County, Arizona	9,685	
Maricopa County, Arizona	9,815	
Yuma County, Arizona	4,671	57,985
Total		66,020

Nearly 88 per cent of the entire area is in Arizona, a little over 10 per cent in New Mexico, and nearly 2 per cent in Mexico.

By a glance at the map, Pl. LXXV, it will be seen that the Gila River proper rises in southwestern New Mexico, near the Arizona line, and flows southwesterly through Arizona to its confluence with the Colorado River. Its total length from the source in New Mexico to the junction with the Colorado River, not including its many windings, is fully 500 miles. Besides the main Gila, the principal tributaries and streams of the basin are the San Pedro and Santa Cruz rivers on the south, and the Salt, Verde, Agua Fria, and Hassayampa rivers on the north.

The floods of the Gila are usually short and violent, the highest water occurring during the months of January and February. During a freshet the river rises in some places from 8 to 12 feet, and increases in width from 300 feet to a mile and a half. It is sometimes impassable for weeks, and has the appearance in places of a sea of muddy water. The season of low water occurs during the months of June and July, the river bed being then dry in places.

AGRICULTURAL LANDS.

The aggregate area in this basin on which crops were raised by irrigation in the year ending June 30, 1890, was found by the Census Office to be 61,857 acres, or 96·65 square miles, this land being along the main river and its tributaries, principally near the foothills, or among them wherever the valleys opened out, leaving room for flood plains. This is between one and two tenths of 1 per cent of the entire area of the basin, or, as the land is principally under 3,000 feet in elevation, is about three-tenths of 1 per cent of this latter class. But in addition to the lands on which crops were raised there is estimated to be an acreage fully twice as large under irrigation, that is, to which water has been brought and perhaps applied in certain years or seasons, but upon which crops were not matured in the census year, owing either to scarcity of water or the undeveloped state of the country.

It is evident from previous statements that this acreage under irrigation is but a small percentage of the total amount which, with ample water, might be cultivated; in fact, this latter total is so large, so much beyond the possibilities of water supply, that estimates as to its extent have little or no practical value. It is sufficient to know that there are in the Gila basin at least 10,000,000 acres of fertile soil, the greater part of which is without water. In other words, the soil and climate are favorable to an expansion of agriculture, which is limited only by the water supply.

Not only does the basin possess all the elements of sucessful agriculture, but it has the advantage of local markets and a constantly increasing demand for the products. The mining regions call for all kinds of food stuffs and forage, and, in fact, many grades of ore depend for successful handling upon a small reduction in cost of living, and consequently, of wages of the miners. There is thus a close interdependence between agriculture and mining, the prosperity of the one reacting upon the other; large crops increase the possibility of working the minerals, and the more laborers there are at the mines the greater is the demand for all kinds of produce..

In this connection it is interesting to note the relation which now exists between the area of the catchment and the area upon which crops have been successfully raised, that is, for which there has been an ample water supply. It is impossible to obtain, without better maps, the exact area of catchment, but assuming for purposes of comparison that it lies above 5,000 feet in elevation, it is found that for every acre irrigated there are in round numbers about 180 acres of catchment area, or for every 1,000 square miles of catchment crops have been raised on a little over 5 square miles. This obviously is a very small ratio, and progress will constantly tend to increase it rapidly at first, and then more and more slowly.

DUTY OF WATER.

This relation between the area of catchment and area cultivated depends directly upon the average duty of water, which, taking the basin as a whole, is very small, although there are instances to show that it can be greatly increased. Calculations have been made that with ordinary care and economy a second-foot should serve 120 acres. It is probable, however, that it will take some years of experience before a majority of the farmers can successfully accomplish this, and more or less hardship may arise in attempting to carry out such economy. Complaints are now made by the farmers that the larger canal companies do not furnish them sufficient water, while the canal superintendents assert that far more than a sufficient amount is allowed.

An approximation of the duty of water in the Gila Valley can be made by knowing the amount which enters through the canyons as compared with the crops irrigated. Eliminating the floods, it has been

found, for example, by the hydrographers of the Geological Survey that about 200 second-feet passed through the buttes above Florence during the year in which, as ascertained by the census, there were about 6,600 acres of crops successfully irrigated. This would give a water duty, measuring the water in the river, of only 33 acres, but it should be noted that a great quantity of this water was wasted, and was used on lands on which crops were not matured. On the lower Salt the measurement of the average flow, deducting the floods, for this time was about 600 second-feet, and about 30,000 acres of crops were raised, giving a water duty of 50 acres. This water duty is also very low, from reasons similar to those given above, but is higher from the fact that the canals were distributed along a greater distance, and much seepage water returned to the river to be used a second time.

Some conception of the average flow of the streams of the basin may be obtained by knowing the acreage of crops successfully irrigated, assuming as correct the statements of the irrigators that these crops demanded all the water available in the streams during the time in which they were maturing. Since there were in the basin 61,857 acres irrigated successfully, it follows that with a water duty of 50 acres to the second-foot the available water supply was at least 1,237 second-feet, or with a water duty of 30 acres to the second-foot, was 2,062 second-feet.

After the water duty has been increased to the greatest possible amount and the limit in this direction has been reached, there must be vast areas suffering for water. Under present methods, as much water as possible is turned out upon the ground in time of flood in order to produce complete saturation and great quantities are used upon the alfalfa and other forage crops. Then, as the rivers fall, water is employed to mature the cereals and vegetables, and finally during a drought the available supply is concentrated upon perennial plants, letting others perish in order to save vines, fruit and shade trees.

There thus arises in this method of progress without water storage a condition of affairs in which the acreage under cultivation adjusts itself to the average perennial supply. In other words, the amount of land on which crops can be raised will be that which the river in an ordinary year will supply with water. If less comes than usual, a portion of these crops must burn under the heat of the sun; if more than usual flows, a larger acreage will mature, and more cuttings of the hay crop can be made. It may be said for the Gila Basin, as well as for the greater portion of the arid region, that this condition has nearly taken place. The acreage of crops planted each year demands all the water or even more than flows during the times when they are maturing and the need is greatest.

While therefore the extent to which irrigation can increase without water storage can not be satisfactorily estimated, it is apparent that this can not be very great. Every irrigator looks forward to the per-

fection of water storage as the only method of relief from present uncertainties and losses.

WATER STORAGE.

In this basin a number of excellent sites are known to exist; two in particular have been so often discussed that it is sufficient merely to refer to them. The first is in Pinal County, 15 miles above Florence, where the Gila flows between two "buttes," forming a canyon 200 feet or more in width, with perpendicular walls on each side. In this canyon a dam of sufficient magnitude would impound, from various estimates, enough water to irrigate a large part of the plains below. The second is at Oatman Flats, in the western part of Maricopa County. The Gila at this point flows between bluffs of limestone from 111 to 126 feet high, and at a distance of 1,195 feet from each other. There is a large storage basin above, in which, by means of a suitable dam, sufficient water could be stored during the storm floods to serve the Lower Gila Valley during the dry season.

Besides these there are numerous places where dams could be constructed and smaller bodies of water stored. It is reported that Salt River, a short distance below the mouth of Tonto Creek, passes through a box canyon with vertical sides rising to the height of 100 feet. A suitable dam built here would impound sufficient water to furnish a part of the Salt River Valley with an abundant supply.

But while there is no doubt as to there being suitable localities in which water can be held, there is some question as to the quantities of water to be depended upon to fill these reservoirs annually. Each year there are short, sudden floods carrying considerable volume of water for a few hours, and at longer intervals, perhaps of three or five years, there are enormous floods, whose violence and duration is phenomenal. These latter, however, are rather to be feared than to be depended upon as beneficial.

The question arises, will the ordinary floods, such as happen every year without exception, fill these storage reservoirs? Can they be depended upon, and do they always carry the requisite amount of water? This is a question, unfortunately, which is far from being answered, and the operation of the Geological Survey being carried on for such a short time, tends rather to increase the doubt than to satisfy it. The year during which the measurements were made was one of comparative scarcity, and these measurements, as shown on later pages, do not give the great quantities of water available for storage that is popularly supposed to exist.

As before intimated, it is necessary to carry on measurements of this class for several years before engineering estimates can safely be prepared. Thus the first steps toward water storage in this basin on any large scale, one in which a majority of the inhabitants will be concerned, is to continue such measurements for a sufficient number of years to determine the necessary facts.

A study of rainfall is interesting and may yield instructive results. If the river flow varied directly with the rainfall, the matter would be greatly simplified, but, unfortunately, the relation which exists between the precipitation as measured in the rain gauges and the amount of water available is not one of direct proportion, but is influenced by so many factors that conclusions based upon the measured rainfall alone are apt to be misleading.

RAINFALL.

Since the water supply comes primarily from the rains, it is well before describing the different portions of the basin in detail to present some of the broader facts concerning the amount and distribution of the precipitation. Compared with the size of the basin, there are but few stations at which rainfall has been measured for a long series of years, and these unfortunately are mainly in the valleys, where the precipitation is least. As a general thing, it may be said that in this basin, owing to the diversity of topography in the higher lands, the rainfall increases with the altitude, and therefore the greater part of the precipitation occurs along the northeastern edge of the basin, while out on the great plains through which the Gila flows, and where the best agricultural land is situated, there is the least moisture, the average at Yuma being less than 3 inches, at Texas Hill, 4 inches; at Maricopa, 5 inches; and at Casa Grande, a little over 4 inches; while, on the other hand, near and among the mountains, or rather the slopes of the edge of the great plateau, the rainfall increases to 10, 15, or even 20 inches and over.

The precipitation of this basin is given in the various publications of the Signal Service, and for the present purpose it is sufficient to present in graphic form some of the general results. On Fig. 226 is given the annual rainfall for seventeen stations, the amount of rainfall for each year being represented by the height of the black blocks, the diagram being similar to that for the Rio Grande Basin. Wherever a blank occurs on this sheet, it signifies that no rainfall observations were made, or that they were incomplete. In looking at this diagram, the most striking fact is the exceedingly irregular character of the rainfall, its variation in amount at one place from year to year, and lack of coincidence for the same year for several places; that is to say, while at one place there is less rainfall for a given year than in the year preceding, for another locality there may be more. There is, however, a certain general variation which may be traced in a broad way; that is taking all of the stations for any one year, the average shows often a decided difference from that of the average of all stations for the year preceding or succeeding. In order to bring this out, the average for all stations in and adjoining the basin has been plotted, as shown in the central figure in the bottom row of the diagram. On examining this, the most notable features are the excessive rainfalls of 1868, 1874, 1878 and 1884, and the diminished rainfalls of 1870, 1880 and 1885,

showing a curious alternation of ten-year periods, which, however, may be regarded as coincidences.

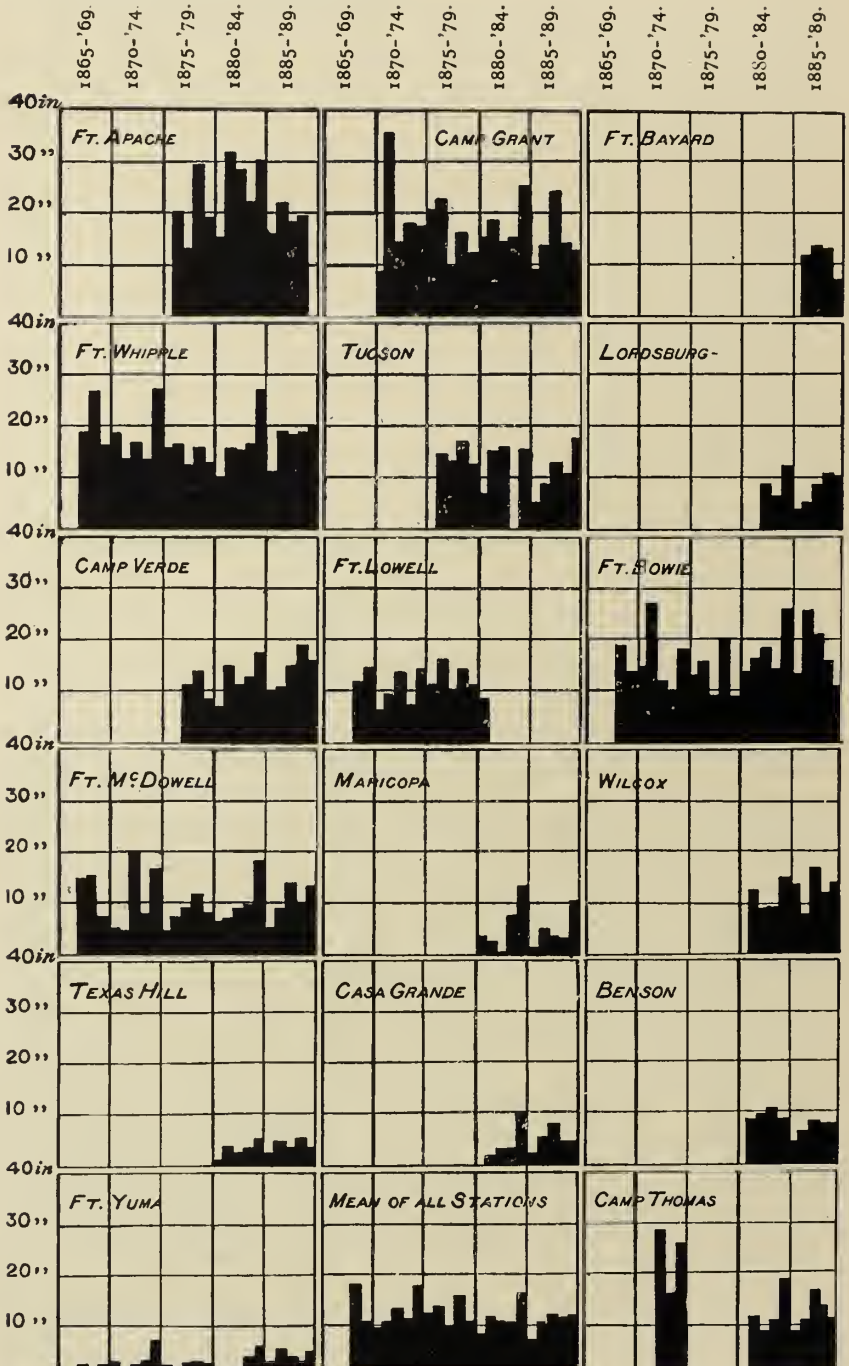
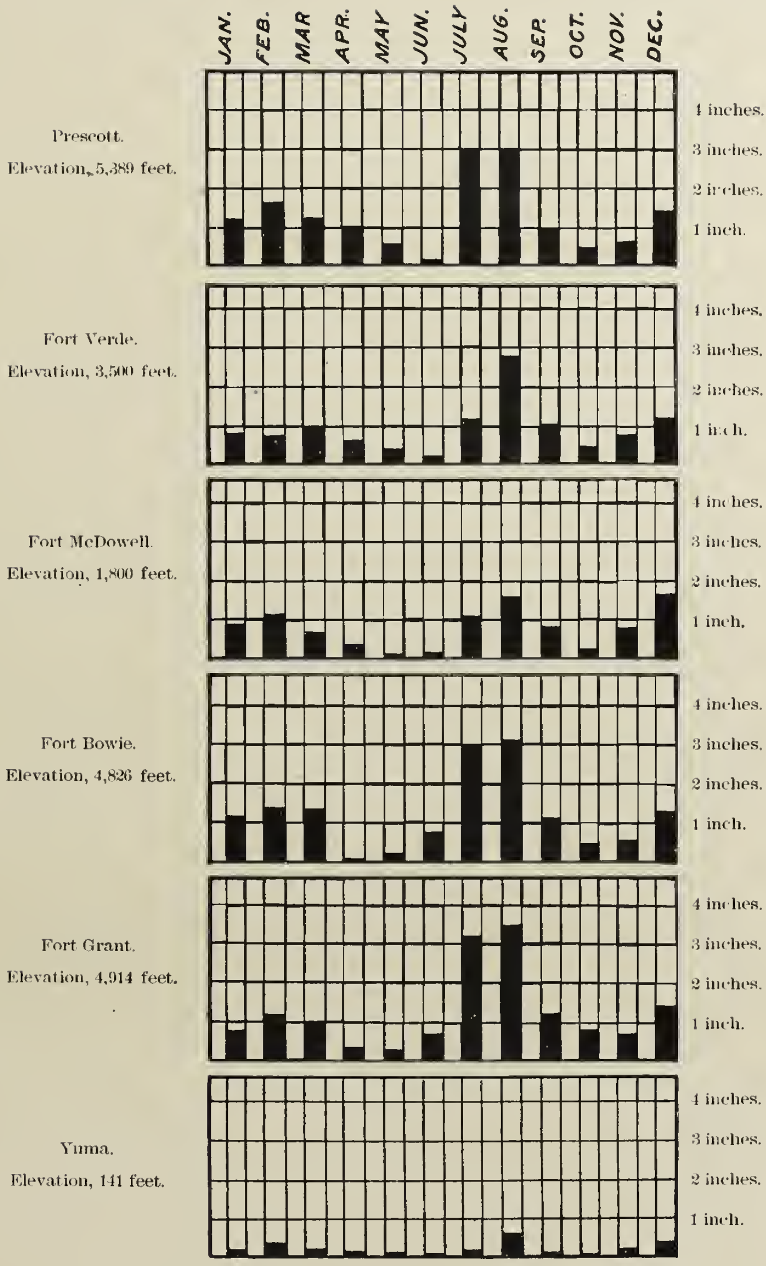


FIG. 226.—Diagram of annual rainfall in the Gila Basin, Arizona.



AVERAGE MONTHLY RAINFALL AT STATIONS IN THE GILA BASIN, ARIZONA.

The year 1884 was an unusually rainy one throughout this basin, as well as throughout a great part of the West, as previously noted, while 1885 was a year of minimum precipitation. Since those years, the average rainfall has been nearly constant, and perhaps diminishing slightly through 1888 and 1889. There is, of course, no regularity about such matters, but a study of the experience of the past is valuable, as indicating the range through which the amount of precipitation has varied, and therefore through which it may alternate again.

While the amount of annual rainfall is important, it does not have such a direct bearing upon agriculture as does the monthly and seasonal distribution of the rain; in other words, a small annual precipitation may be compensated for by a distribution of rainfall such that it all occurs during the months when most needed. On the other hand, a large annual precipitation may be of small use to the farmer from the greater part occurring at times when the water is not needed, and when it runs off into the rivers. Pl. LXXVI shows graphically the relative amount of rainfall during the months for six different stations. This is the average of from twelve to fifteen years,[1] and while it does not represent the amount which may be expected to fall on any one month, it does show the distribution through long periods of time. The most notable feature of this diagram is the gradual decrease of the rain from February to June, the sudden increase in July and August, a second diminution in the fall, nearly, though not quite, to that of early summer, and a second gradual increase in the winter to an amount about half that of the summer.

The relation between the rainfall and the amount of water which flows in the river, commonly known as the run-off, is not a matter of direct proportion, as before noted, on account of the many modifying circumstances. A rainfall of 1 inch may or may not cause a greater rise than one of half an inch, depending upon the rate at which it falls. For example, a long-continued, gentle rain may slowly saturate the ground and contribute very little to the run-off, while, on the other hand, the same amount of water falling in a sudden local storm often causes an immediate response in the streams and produces a violent flood. Although a knowledge of the rainfall can not give information as to the water flowing in a river, yet it is of the greatest value in other connections.

In this connection Pl. LXXVII, showing a portion of the drainage area of the ill-fated Hassayampa Reservoir, is introduced to exhibit the characteristic topography of the higher part of the Gila Basin. In the background are shown the steep slopes of the mountains, almost bare of vegetation, and from which in time of rain the water runs immediately into the gullies and canyons. This view shows the Hassayampa Reservoir shortly after it was filled with water for the first time, the

[1] Charts showing the normal monthly rainfall in the United States extracted from the monthly weather review, with notes and tables prepared under the direction of Gen. A. W. Greely, Chief Signal Officer; Washington, 1889.

tops of the higher trees still appearing above the water. The vegetation throughout that country is very scanty, and, as shown in the foreground, there is none of the smaller growth and carpet of grass so common in the humid regions.

UPPER GILA DISTRICT.

The headwater basins of the Gila, as shown on the map, are as follows: Upper Gila, San Pedro, Verde, and Upper Salt. The Trunk River divisions are the Middle Gila, Lower Salt, and Lower Gila, while the principal lost river basins are the Agua Fria, Hassayampa, and Santa Cruz, each of which will be discussed in order.

The Upper Gila district or headwaters of the main Gila may be considered as including that part of the basin from the highest catchment down to the buttes above Florence, excluding, however, the San Pedro. This area embraces that portion of the basin from which the most water may be supposed to come, as well as certain large bodies of irrigated and irrigable lands. The total area is 10,930 square miles, comprising 3,893 square miles in Socorro County; 156 square miles in Sierra, and 2,818 in Grant County—these three counties being in New Mexico; and in Arizona—4,220 square miles in Graham County; 880 square miles in Gila County, and 530 square miles in Pinal County.

The elevation ranges from 3,000 feet up to 10,000 on the highest peaks. The principal streams, besides the Gila itself, are the San Francisco River and its branches, the Gila Bonita, and the Mogollon River. The San Francisco is a perennial stream, which derives its principal supply from melting snow, and becomes very low, although it has not actually become dry before the summer rains.

The Gila in this portion of its course flows throughout the year, and is subject to sudden and violent floods, especially during the summer season. The supply for this district is comparatively ample, and therefore no attempt has been made to increase it by storage. During 1889 and 1890 crops suffered greatly on account of the scarcity of water, for, judging from general report, there was less water than during the previous decade. It is probable, however, that the supply was ample for the acreage irrigated in the census year. In general, for wheat, barley and oats, water was plentiful, but late crops often suffered and were lost.

In the valleys comprised within this district crops to the extent of 9,137 acres, or 14·3 square miles, were raised by irrigation in the census year. This amounts to a little over one-tenth of 1 per cent of the total area of the district. The largest body of irrigated land is in the Pueblo Viejo Valley, extending from the canyons above Solomonville westward. In this valley, besides the land under crop, there are large tracts to which water can be brought by the ditches at present in operation, the names of which, as reported to the survey by Mr. T. E. Farish, in 1889, are given below. Under the head of acres is the probable acreage which the ditch may be made to cover.

HASSAYAMPA RESERVOIR.

Ditches and irrigable lands.

	Length.	Covers.		Length.	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Montezuma	9	6,000	Mejia	5	2,000
San Jose	7	3,000	Maxey	8	4,500
Union Canal	8	6,000	Oregon	5	2,500
Central Canal	12	6,000	Nevada	6	3,000
Sunflower Canal	3	1,500	Darby	4	1,000
Smithville Canal	5	2,000	Michelena	4	1,500
Gonzales	5	2,000			

Besides the above there are two or three small private ditches, covering in the aggregate about 4,000 acres, bringing up the entire acreage which could be reclaimed by ample water to 45,000 acres. In Pinal County there are three private canals between the mouth of the San Pedro and the town of Riverside, as follows:

	Length.	Covers.
	Miles.	*Acres.*
Shields	2½	480
Winkleman	1½	480
Brannaman	1¼	320

Many of the canals given above have sufficient water at all times for the area under crop, while others are reported to be dry for a few weeks in June and July. The question of water storage, however, has not as yet attained great prominence, as by far the greater part of the tilled lands in this basin along the river have ample water, and there are still tracts in various localities which may, with proper care and economy of water, be brought under irrigation.

THE SAN PEDRO DISTRICT.

The San Pedro rises in Sonora, Mexico, and flows northerly through Cochise County, a corner of Pima, and the western end of Pinal County, Arizona, entering the Gila below Dudleyville, 45 miles above Florence. This total area comprises about 2,820 square miles, of which 120 miles are in Mexico, 1,900 miles in Cochise County, 267 in Pima, and 533 in Pinal County. The limits of this district can not be accurately defined as there are no good maps of this extreme southern portion of the United States, and the outlines can be sketched only in a general manner. Eastward of this district and south of the upper Gila district is a large area of about 5,700 square miles, which has been included within the hydrographic basin of the Gila, but in which there are no large streams, whatever rainfall there is being usually evaporated before streams of any size are formed.

The water supply of this basin comes almost entirely from the San Pedro River, which is perennial, but which, like all other streams of the basin, fluctuates greatly. The season of scarcity usually occurs in May and June, the rains of summer tending to swell the river in July, Au-

gust, and September. No attempts at storage have been made, but the irrigators appreciate the necessity of so doing, and regard this matter as of first importance. The supply is considered sufficient for the small grains and hay, but for late crops of corn and beans there is sometimes a scarcity. It is reported that there was more water in 1890 than for some years previous.

The river, receiving most of its waters from a country of very light snowfall, depends for the greater part upon the showers of summer. For many miles it flows over a sandy bed between high banks. During the rainy season the waters rise suddenly, even, it is reported, to 12 feet in places, assuming then the character of a torrent. In droughts it shrinks to an insignificant stream of clear water, sinking into the sands and again reappearing, where the ground water is forced to the surface by impervious layers or bed rock.

In the upper San Pedro Valley are several thousand acres devoted to stock raising, much of which can, however, be irrigated in time by a careful conservation of the waters. For a distance of over 60 miles along the river small ditches have been taken out. The soil of the valley is fertile, producing good crops of alfalfa, wheat, oats, barley, vegetables, and various fruits.

The following is a list of the canals, as given by Mr. T. E. Farish in 1889:

Canals of San Pedro Valley.

	Length.	Covers.		Length	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Brown	1¼	160	Watterman No. 2	1½	320
Cook	1½	200	Watterman No. 1	1½	320
Dodson	2	320	Swingle	2	480
Pusch	2	640	Harrington	1¾	480
Bates	1½	160	Latten	1	80

In the lower portion of its course the river is in places dry, owing to the diversions made by a large number of small canals. In addition to the main stream there are in the mountains, at the outlets of various canyons, a number of small springs, whose waters have been used for agricultural purposes and which are of considerable value to the owners, but these do not form a notable feature in the water supply of the district. The total area upon which crops were raised in this district during the census year was 2,672 acres, or nearly 4·2 square miles, or 0·15 per cent of the entire basin.

Water storage is urgently needed, and there are unquestionably facilities for this, the great obstacle being the lack of information as to the amount of water available. Measurements of water in this basin were begun at a station near Dudleyville, to obtain the amount discharged into the Gila. The station was placed at this point largely from the fact that it could be operated in connection with the gauging

station at the Buttes, above Florence. The measurements were begun on April 9, 1890, and continued until the hydrographic fieldwork was suspended. The results are as follows:

San Pedro—Dudleyville, Arizona.

[Drainage area, 2,870 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per square mile.
1890.	*Sec. feet.*	*Sec. feet.*	*Sec. feet.*	*Acre feet.*	*Inches.*	*Sec. feet.*
April 9 to 30	21	5	14	833	·005	·005
May	9	5	6	369	·002	·002
June	5	1	3	179	·001	·001
July	225	1	13	800	·005	·005
August	507	102	295	18, 140	·121	·105
Total					·134	

It so happened that the gaugings were made during a year when the floods were apparently small, although at a season when they were liable to occur with violence. After the work was suspended there were several periods of high water, but the quantities discharged can not be computed, as the gauge rod was injured. Judging from the reports of residents of the valley, this was a year of minimum river flow, so that the measurements must be considered as far below the average.

THE MIDDLE GILA DISTRICT.

The middle Gila district is a trunk river division, and depends for its water supply upon the amount which comes from the two districts above mentioned, namely, the upper Gila and the San Pedro. The limits of this district are somewhat arbitrary, the district being considered as extending from the Buttes above Florence to the junction of the Gila with the Salt, and including on both sides of the river that portion of the great plain which can be irrigated from the Gila River. There were in this district 6,619 acres of crops irrigated, as shown by the census of 1890. The water supply for this land comes wholly from the Gila River, and the development of agriculture within the district depends upon the conservation and economic employment of this water. In the latter part of June the bed of the river is often dry, its water being diverted by the numerous canals of this district. Floods are liable to occur with great violence in July and August, as well as in January, February, and March. There is usually sufficient water to mature one crop, but it is reported that the second crop has been lost repeatedly. According to the statements of the irrigators, the year 1890 was one of the dryest known, while during 1889 the supply may be considered as about at an average.

In the Middle Gila Valley, beginning just below the canyon, 12 miles above Florence, the following canals were reported by the hydrographers as taking water from the river in 1889:

Canals of the Middle Gila Valley.

	Length.	Covering.		Length.	Covering.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Moore's	3	300	Montezuma	6	1,000
McClelland	3	300	Pat Holland	7	1,000
Sharp	3	160	Alamo Amarillo	7	1,000
Stiles	4	300	Brady	4	1,000
Swiss	2	200	Adamsville	4	1,000
Brash	4	400	White	3	200
Florence	43	20,000	Walker & Dempsey	3	300

The amount of water available for this basin was accurately determined by the Geological Survey during about one year; but their work was stopped at the end of this time by lack of further appropriation. The gauging station was established at the Buttes, about 15 miles above Florence, at a location well known from the favorable advantages which it offers for the storage of water. Here measurements were made from August 26, 1889, to September 1, 1890, the results of which are given in the following table, and are shown graphically on Pl. LXXVIII. According to the statements of men who have been for some years in that district, the water supply of that year was lower than usual. This assumption, however, will not hold if diversions of the water continue to be made in the Upper Gila district, where there is still a large acreage of good arable land to be brought under cultivation.

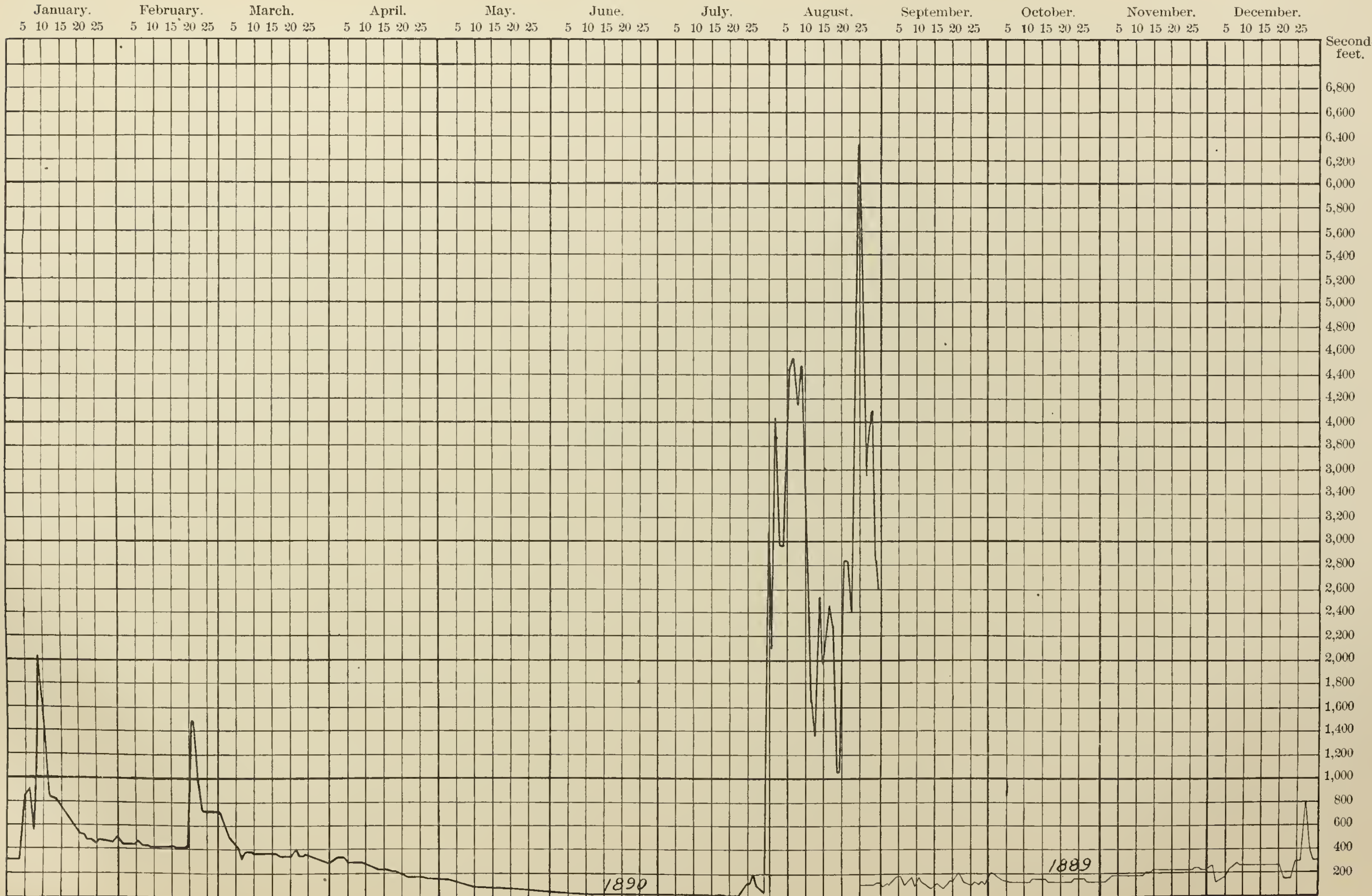
Gila River, Buttes, Arizona.

[Drainage area, 15,370 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per square mile.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-feet.*	*Inch.*	*Second-ft.*
Aug. 26–31	124	110	115	7,072	·008	·007
September	210	90	128	7,616	·009	·008
October	210	140	157	9,655	·014	·012
November	250	156	212	12,614	·015	·013
December	890	124	275	16,912	·020	·018
1890.						
January	2,100	310	680	41,820	·051	·044
February	1,514	405	578	32,079	·039	·037
March	710	300	387	23,800	·029	·025
April	333	158	238	14,161	·017	·015
May	150	35	87	5,350	·007	·006
June	35	27	28	1,666	·002	·002
July	3,112	11	130	7,995	·009	·008
August	6,330	1,115	3,137	192,925	·235	·204
Total, 1 year			6,037	366,593	·447	
Mean			503			

In the latter part of the above table is given the depth of the run-off in inches, and it is of interest to note the small amount of this and the relation between it and the depth of rainfall as measured at various points in and near the basin.

In the following table the depths of precipitation is given as published in the reports of the Signal Service for the months during which



DAILY DISCHARGE OF THE GILA RIVER AT THE BUTTES, ARIZONA.

the river gaugings were made, and at the bottom is the mean of the depths of the stations reporting. If it be considered that this in a general way represents the average for the basin, or at least varies with the average rainfall in the basin, a comparison can be made between the rainfall and run-off. The heavy rains of September do not appear to have had an immediate influence on the river. On the other hand, the decreasing rainfall in September, October, and November is accompanied by a gradual increase in discharge of the river, indicating that while the precipitation may be less in amount, yet, as winter approaches the showers may have a greater and greater influence on the river discharge.

Comparing the total of the monthly mean precipitation—15·56 inches—with the total depth of run-off for the year—0.447 inch—it appears that a little less than 3 per cent of the rainfall of the basin reaches the gauging station, under the assumption that this average of the measured rainfall represented that for the entire basin. If no diversions of water for irrigation had been made in the upper Gila and San Pedro districts, this percentage would have been larger, reaching possibly as high as 5 per cent. It is to be noted that over one-half of the run-off of the entire year came in August.

Monthly precipitation at stations in and adjoining the Gila Basin, in inches.

Station.	1889.				1890.							
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
Bisbee	3·79	0·38	0·20	0·29	2·34	0·20	0·24	0·15	0·00	0·03	6·07	5·71
Dos Cabezas	0·58	1·11	T	0·12	1·28	......	0·08	0·95	0·00	0·03	3·90	5·07
Dragoon	0·18	......	0·00	0·97	2·11	0·43	0·00	0·32	0·00	0·00	4·09	4·73
Dudleyville	1·55	0·78	0·82	1·88	1·63	1·46	0·52	0·75	......	T	......	......
Fort Bayard	2·19	0·67	0·00	T	1·40	T	0·11	T	0·00	T	4·17	3·86
Fort Bowie	2·79	0·74	T	0·57	0·78	0·23	0·03	0·59	0·00	T	4·97	4·06
Fort Grant	0·69	0·94	0·16	1·11	1·58	0·46	0·46	0·92	0·01	0·20	3·24	4·54
Fort Huachuca	2·46	0·04	0·14	0·75	1·50	0·10	T	0·34	0·00	0·00	4·38	4·49
Fort Thomas	0·38	0·26	0·34	1·18	1·92	0·49	0·45	1·21	0·00	T	2·02	4·11
Pantano	2·52	0·04	0·00	0·96	......	0·75	0·15	0·79	0·00	0·00	2·49	6·30
San Carlos	2·13	0·71	0·50	2·05	2·10	1·40	0·88	1·31	0·00	0·00	2·25	3·26
Silver King	0·97	1·17	0·83	5·23	3·77	2·93	0·64	2·63	0·00	......	......	......
Teviston	2·30	0·60	0·20	0·20	3·80	T	0·20	3·00	0·00	0·00	5·20	4·00
Wilcox	2·79	0·80	0·02	0·50	1·61	0·35	0·11	0·63	0·00	0·15	2·64	5·20
Mean	1·80	0·63	0·23	1·13	1·98	0·67	0·27	0·97	0·00	0·03	3·24	4·61
Run-off	0·009	0·014	0·015	0·020	0·051	0·039	0·029	0·017	0·007	0·002	0·009	·235
Per cent	0·5	2·22	6·5	1·7	2·57	5·82	10·7	1·7	0·00	6·6	2·7	5·0

The most important question is as to how much water could have been saved during this year, if a suitable dam had been at this place. It is evident that not all the water could be held; a certain amount must be allowed to flow down the channel for the ditches below.

It is also necessary to assume that there would be a constant loss of water by evaporation. The measurements of this factor have not been continued for a time sufficiently long to give a large range of results, but from an examination of these and other data the following rate has been assumed in round numbers:

Loss by evaporation from a water surface.

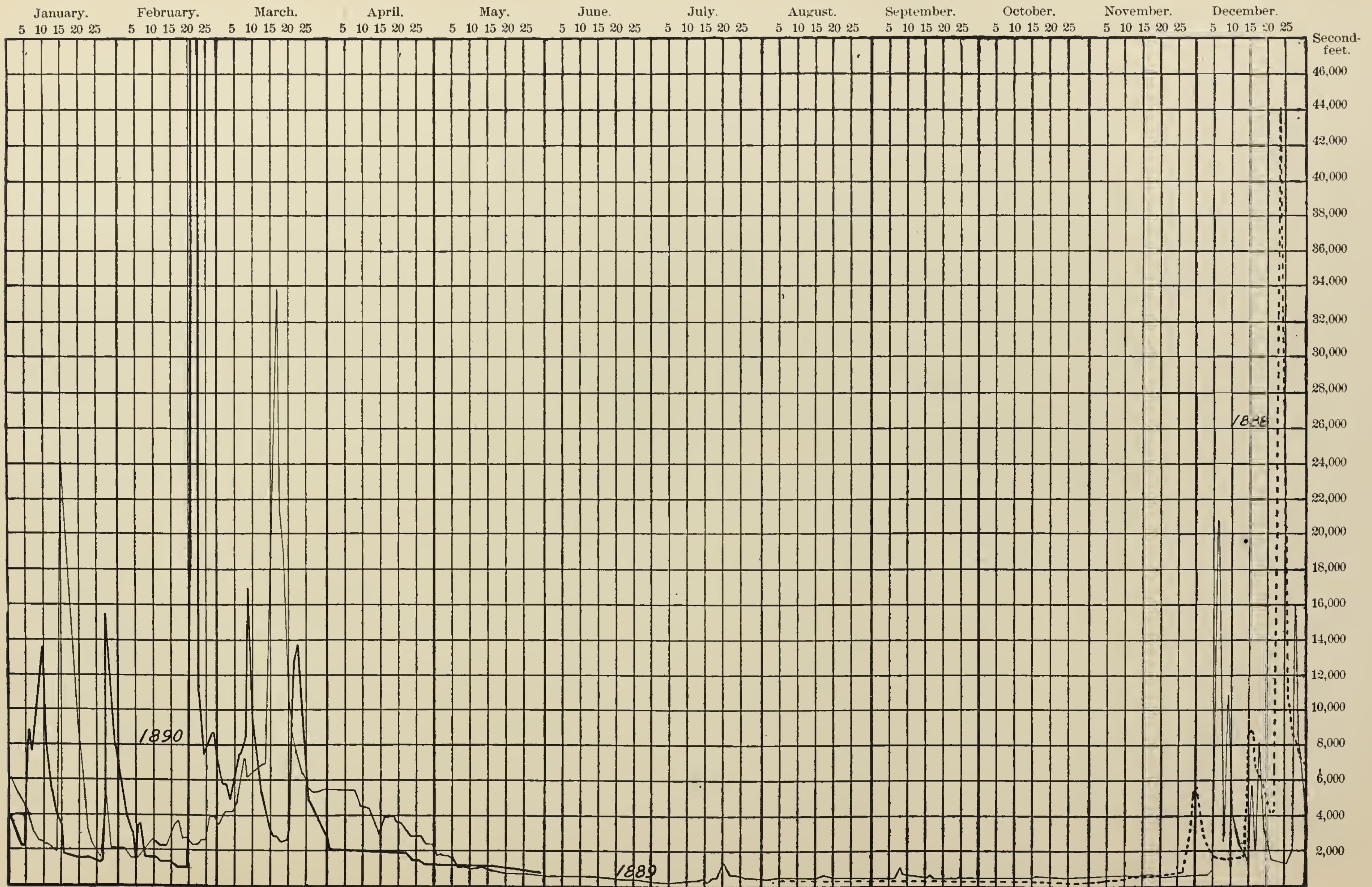
Month.	Quantity.	Month.	Quantity.
	Inches.		*Inches.*
January	3	August	13
February	4	September	10
March	6	October	6
April	7	November	5
May	10	December	4
June	11		
July	12	Total	91

In order to obtain general ideas concerning the amount of water which could have been stored during the year in which measurements were made, one or two examples may be given, taking different rates of outflow for the various months. For any given acreage under cultivation a certain amount of water must be allowed to flow in the river all the year round, less being needed in winter than in the heat of summer, but some being used even in the former season, especially on forage crops. These examples are placed in tabular form for convenience.

In the first case it is assumed that no water is held during September, October, and November of 1889, but that in December, January, and February only 150 second-feet are allowed to flow in the river; in March, April, and May, 250 second-feet; in June, July, and August, 300 second-feet. The first column gives the months. The second column the average inflow of the supposed reservoir in second-feet; that is, the measured amount of water flowing in the river. The third column gives the amount assumed to be discharged steadily from the reservoir. The fourth column gives, in round numbers, the loss by evaporation in acre-feet, making certain assumptions as to the size of the reservoir and consequent area of surface exposed to evaporation. The fifth column gives the amount of water which is left in the reservoir at the end of each month.

Month.	Inflow.	Outflow.	Evaporation.	Bal. at end of month.
1889.	*Sec. feet.*	*Sec. feet.*	*Acre-feet.*	*Acre-feet.*
September	128			
October	157			
November	212			
December	275	150	100	7,400
1890.				
January	680	150	500	39,760
February	578	150	1,000	62,728
March	387	250	2,000	69,222
April	238	250	2,000	66,502
May	87	250	3,000	53,396
June	28	300	2,000	35,076
July	130	300	2,000	22,536
August	3,137	300	4,000	193,036

In the second case, all of the water being allowed to flow during September and October, 200 second-feet is discharged into the river during November, December, January, and February, and 250 second-feet in March and April. This amount is then increased to 300 second-feet in



DAILY DISCHARGE OF THE SALT RIVER ABOVE PHENIX, ARIZONA.

May and 350 in June, July, and August, leaving a balance at all times in the reservoir as shown in the fifth column.

Month.	Inflow.	Outflow.	Evaporation.	Bal. at end of month.
1889.	*Sec. feet.*	*Sec. feet.*	*Acre-feet.*	*Acre-feet.*
September	128			
October	157			
November	212	200	15	700
December	275	200	80	5,230
1890.				
January	680	200	400	34,330
February	578	200	1,000	54,320
March	387	250	2,000	60,760
April	238	250	2,000	58,045
May	87	300	2,500	42,445
June	28	350	2,000	21,295
July	130	350	1,500	6,275
August	3,137	350	4,000	170,275

The amount of land which would be irrigated by the streams which have been assumed in these examples as coming from the reservoir will vary largely with the character of crop, especially the proportion of forage plants, these requiring water at all seasons. A conservative estimate, however, of 75 acres to the second-foot will probably cover all contingencies. This duty, as is recognized, is small, from the fact that the water is returned to the river from the reservoir and is not taken directly by short canals upon the land. In the first case assumed in these examples of a flow of 300 second-feet in June, July, and August, at least 22,500 acres can be covered, and in the second case, with a larger percentage use of water during the winter, 26,250 acres can be irrigated.

These examples and an infinite variety of others which might be taken, using different combinations of figures, merely serve to show that even in a dry year sufficient water can be held to protect a large acreage and render irrigation a matter of certainty. Other engineers, in figuring the amount of water available, will undoubtedly take other values, and in most cases they will estimate that a far larger acreage can safely be covered, since these examples are taken with a wide margin of safety.

THE VERDE DISTRICT.

The Verde district embraces the drainage basin of the Verde River and its tributaries, having a total area of 6,000 square miles, of which the greater part is in Yavapai County, only 700 square miles being in Maricopa County. In this district 1,948 acres of crops were irrigated successfully in the year ending June 30, 1890. The water supply in general is good, and a far larger area, now partly irrigated, can be watered.

Among the principal tributaries of the Verde are Walnut, Granite, Oak, Beaver, and Clear Creeks. Walnut Creek is dry during a portion of the year, its waters being entirely diverted upon the adjacent land.

On Granite Creek the supply is reported to be ample for the acreage under irrigation, but there is more land needing the waste waters of the floods. Oak Creek supplies an amount more than sufficient for the lands in the vicinity of Cornville. The other streams entering below carry larger quantities of water than is used at any time.

The largest body of irrigated and easily irrigable lands is in the Verde Valley proper, which is situated in the southern part of Yavapai County, extending from a canyon 20 miles or more above Camp Verde to another narrow pass about 10 miles below the fort. In this valley large crops of alfalfa, barley, oats, wheat, corn, and potatoes are reported to be raised, as well as apples, pears, plums, peaches, and apricots. The Verde River here flows continuously, with an occasional flood from local rains. The water supply is good, but crops have suffered from accidents to canals or difficulty of turning the water into them.

Measurements of the discharge of the Verde were attempted at a point about a mile above its junction with the Salt River, in order to obtain the amount discharged and its relative importance. The station at this point was operated in connection with one on the Salt River, about a mile above the Verde, and observations at both points were carried on during a large portion of the summer and fall of 1889. It was found impracticable, however, to obtain the daily heights on account of the distance of these stations from the homes of persons who were competent to act as gauge observers, and the difficulty of measuring these rivers in time of flood necessitated the abandonment of the work in order to concentrate all efforts on the Gila River.

The results of the measurements are given in the following table, and they may also be found in greater detail in the previous annual report. These do not show a very decided fluctuation of the river, but serve to give definite ideas as to the ordinary summer discharge of this stream:

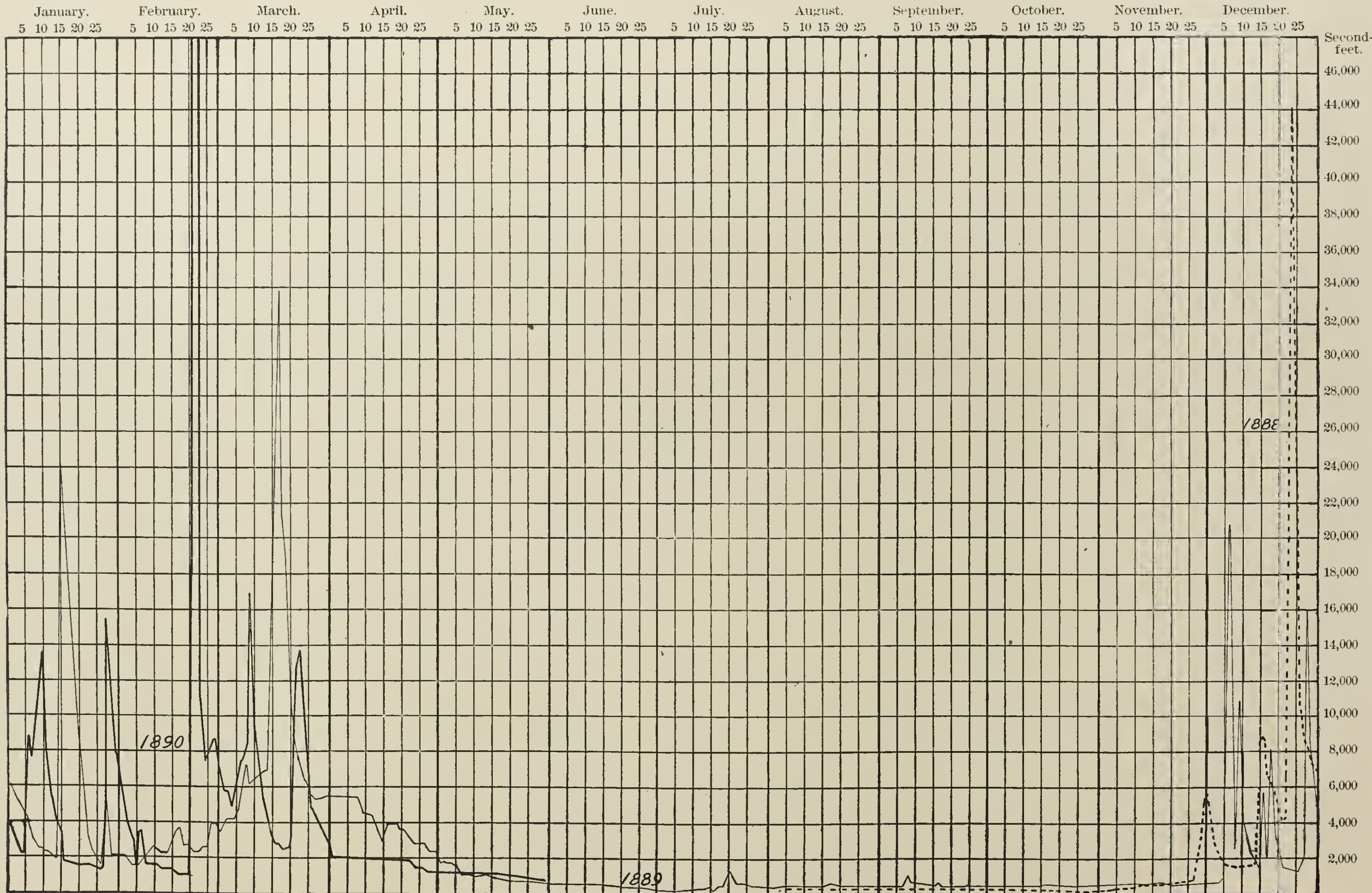
Verde River, 1 mile above Salt River.

[Drainage area, 6,000 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inch.*	*Sec.-feet.*
August 14–31	480	154	207	12,730	·04	·03
September	340	140	192	11,424	·03	·03

THE UPPER SALT DISTRICT.

The Upper Salt Basin lies between the Verde and the Upper Gila, and is similar in many respects to these headwater basins. The total area is 6,260 square miles, of which 927 miles are in Yavapai County, 1,935 miles in Apache, 2,430 miles in Gila, 420 in Graham, 424 in Maricopa, and 124 in Pinal County. Owing to the mountainous character of this district there were only 815 acres of crops cultivated by irrigation



DAILY DISCHARGE OF THE SALT RIVER ABOVE PHENIX, ARIZONA.

in the census year. The valleys are in general narrow, the only opening of any importance being along the Salt River, between Pinal Creek and Tonto Creek. The water supply is, therefore, ample for all the accessible land of this district.

This basin may be taken as including the area of the Salt River headwaters down to the junction with the Verde. The country is rugged and heavily timbered at the higher elevations, and there are not many large valleys along the river where agriculture can be carried on. The principal streams entering from the north are Black River, Bonita, White Mountain, Carrizo, Cibicu, Canyon, Cherry, and Tonto Creeks, and from the south Pinal and Pinto Creeks. The principal agricultural land of the basin extends from a point below Pinal Creek to Tonto Creek, some farming being carried on also along Sally May Creek and Tonto Creek.

Measurements of the water flowing out of this drainage basin were made, as stated above, at a point about a mile above the junction with the Verde, being carried on at the same time that measurements were made on that river, and later at a point in the canyons about 20 miles above the Verde. The results of these latter measurements are given in the following table, which exhibits the ordinary range in amount of the summer water:

Salt River in canyon—20 miles above the Verde.

[Drainage area, 5,880 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Sq. mile.
1890.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inch.*	*Sec.-feet.*
May 28-31	520	520	520	31,980	·10	·09
June	520	193	298	17,731	·06	·05
July	375	185	215	13,222	·04	·04
August 1-28	2,200	600	1.362	83.763	·27	·23

THE LOWER SALT DISTRICT.

The Lower Salt district is the principal subdivision of the Gila Basin, since it includes the largest area of irrigated land and the greatest canal systems of Arizona. It may be said to begin at the junction of the Salt and Verde, and to extend to or below the great bend of the Gila, including on each side some of the most fertile land of the Territory. The total acreage on which crops were raised by irrigation in the census year was 29,171 acres. This is but an insignificant portion of the total amount on which products might be raised with a sufficient water supply, for, as previously stated, there are enormous tracts of fertile land, whose extent is so great that no probable increase of water supply can cover them.

The Salt River is the only source of water; the situation here is similar in many respects to that of the middle Gila district, but has the advantage that the headwater districts do not contain such large

bodies of irrigable land as do the headwaters above the middle Gila. There is said to be ample water for the present acreage cultivated in the fall and spring, but in summer the supply is scarce, so much so that crops have been lost, and trees and shrubs have perished for lack of water.

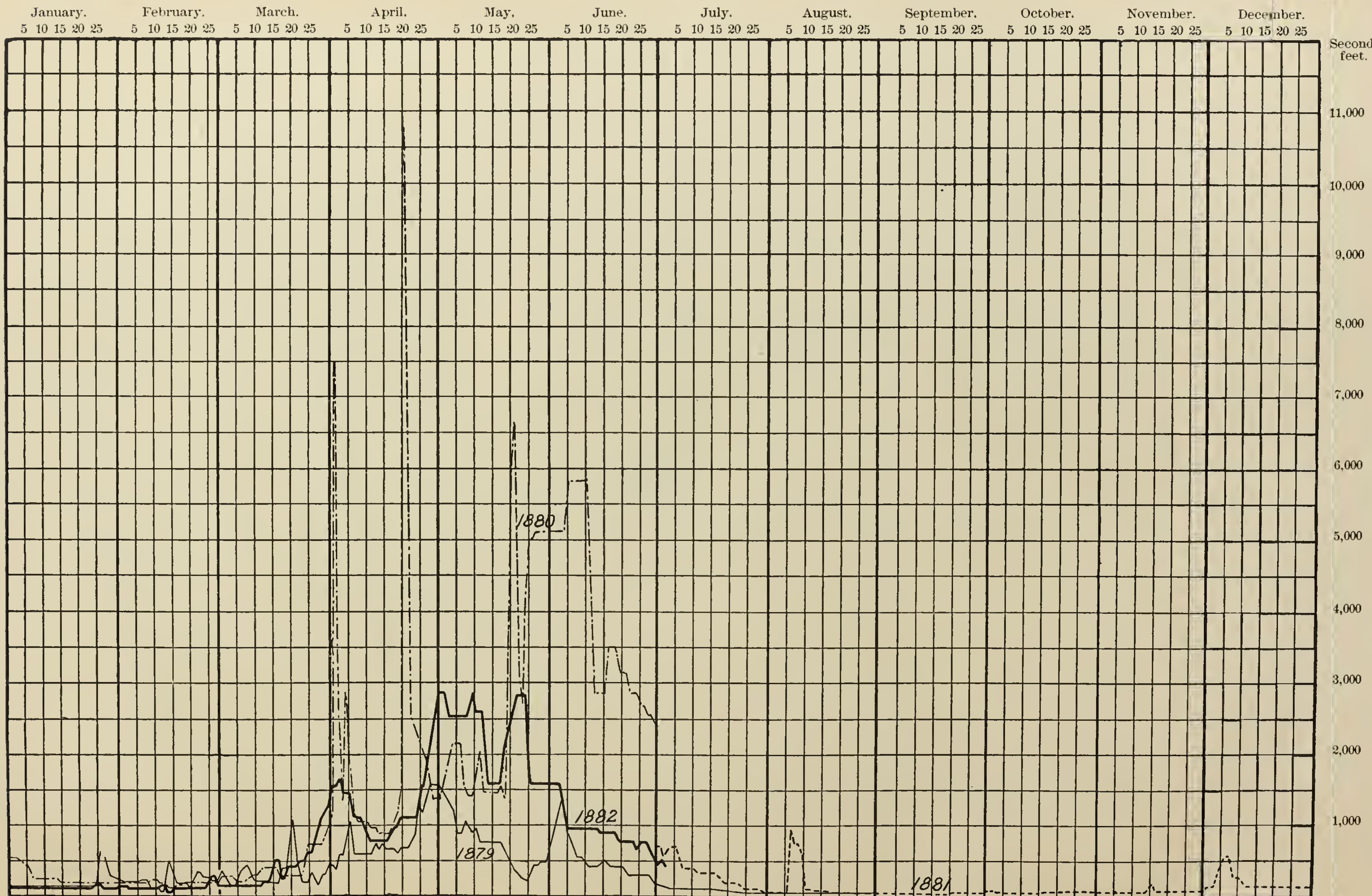
In the Salt River Valley, in Maricopa County, the following canals were reported in 1889 as being taken from Salt River:

Canals.	Length.	Canals.	Length.
	Miles.		*Miles.*
Arizona	40	Utah	6
Grand	22	Farmers	5
Maricopa	14	Highland	22
Salt River Valley	18	Dutch Ditch	4
San Francisco	9	Monterey	4
Tempe	19	Griffin	3
Mesa	9		

It may be added that, excepting in floods, all the water in Salt River has been utilized, and nothing more can be done in the way of land reclamation without the construction of storage reservoirs. If this were done it is estimated that sufficient water could be impounded during the storm floods to reclaim double the area now under cultivation. The soil is very productive. Large crops of wheat, barley, and alfalfa are grown, and fruits of all descriptions flourish and yield bountifully.

Measurements of the amount of water entering this subdivision were made, as before mentioned, by establishing stations on the Salt and Verde rivers, a short distance above their junctions, but these were continued only a few months as it was found impracticable with the small force available to keep up the work. Estimates of discharge, however, have been prepared by Mr. Samuel A. Davidson, engineer of the Arizona Canal Company. These are based upon weir calculations of the water flowing over the submerged dam built by this company at their headworks. These were begun in August, 1888, and daily observations continued up to the present time, the results of which are kindly given by Mr. Davidson, as shown in the following table. Measurements of this character being based upon certain assumptions and the use of constants determined in a small way, their degree of accuracy is open to question, but, at least, these measurements, or rather the computations based upon them, have a great value as showing the relative amounts of water in the different months and seasons.

On Pl. LXXIX is shown graphically the daily mean discharge as computed by Mr. Davidson, and the irregular character and extraordinary fluctuations of the stream are clearly brought out. The most noticeable feature is the great flood of February 21, 1890, when, according to Mr. Davidson's computations, the discharge increased suddenly from 1,000 second-feet to over 143,000 second-feet. This, however, is eclipsed



DAILY DISCHARGE OF THE KAWEAH RIVER AT HOMER'S RANCH, CALIFORNIA, 1879 TO 1882.

by the flood of February 18 to 25, 1891, which, is not shown upon Pl. LXXIX, the data being received too late for illustration. On February 17 the mean discharge was 835 second-feet, increasing the next day to 154,000 second-feet, and on the 19th to 276,000. This first flood diminished rapidly, averaging on the 20th only 69,100, and on the 22d 14,890. This was followed by a second swell greater than the first, the flood increasing until on the 24th a maximum of 300,000 second-feet was reached. This subsided almost as rapidly as it came, so that by the second day after the river was carrying less than 15,000 second-feet.

This flood was very destructive, carrying away bridges and portions of canals, submerging great areas in the Gila Valley, and causing a sudden rise in the Colorado, as shown on Pl. LXXIV, the greatest flood for that decade at least. The Arizona Canal Company's weir across the Salt River was damaged, a portion of the canal washed out, and the channel of the stream so altered that computations of daily discharge could no longer be made without new data.

Salt River, Arizona Dam, Arizona.

[Drainage area, 12,260 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per sq. mile.
1888.	*Sec. feet.*	*Sec. feet.*	*Sec. feet,*	*Acre-feet.*	*Inch.*	*Sec. feet.*
August	....	....	350	21, 525	.03	.028
September	....	....	350	20, 825	.03	.028
October	350	300	331	20, 356	.03	.027
November	5, 760	425	842	50, 099	.08	.068
December	43, 489	1, 665	6, 698	411, 927	.63	.545
1889.						
January	24, 953	1, 665	5, 947	365, 740	.56	.48
February	3, 940	1, 534	2, 605	144, 577	.22	.22
March	33, 794	3, 563	8, 745	537, 817	.82	.71
April	5, 559	2, 496	3, 975	236, 512	.36	.32
May	1, 784	622	1, 039	63, 898	.10	.08
June	615	356	470	27, 965	.04	.04
July	1, 311	334	495	30, 522	.05	.04
August	755	389	417	25, 645	.04	.03
September	1, 172	389	521	31, 000	.05	.04
October	704	319	440	27, 060	.04	.04
November	629	532	576	34, 272	.05	.05
December	25, 371	557	5, 686	349, 689	.53	.46
1890.						
January	15, 750	1, 376	4, 982	306, 393	.47	.40
February	143, 288	1, 045	10, 097	560, 383	.86	.82
March	17, 228	2, 566	6, 421	394, 891	.60	.52
April	2, 077	1, 369	1, 840	109, 480	.17	.15
May	1, 369	630	914	56, 211	.09	.08
June	672	397	511	30, 404	.05	.04
July	872	397	524	32, 226	.05	.04
August	7, 734	1, 114	3, 885	238, 927	.37	.32
September	3, 685	725	2, 339	139, 170	.21	.19
October	7, 465	753	2, 768	160, 232	.25	.23
November	30, 504	766	4, 717	280, 661	.43	.38
December	30, 366	1, 110	6, 259	384, 928	.59	.51
1891.						
January	17, 127	1, 060	3, 416	210, 084	.32	.28
February	300, 000	825	39, 201	2, 175, 655	3.32	3.10

THE LOWER GILA DISTRICT.

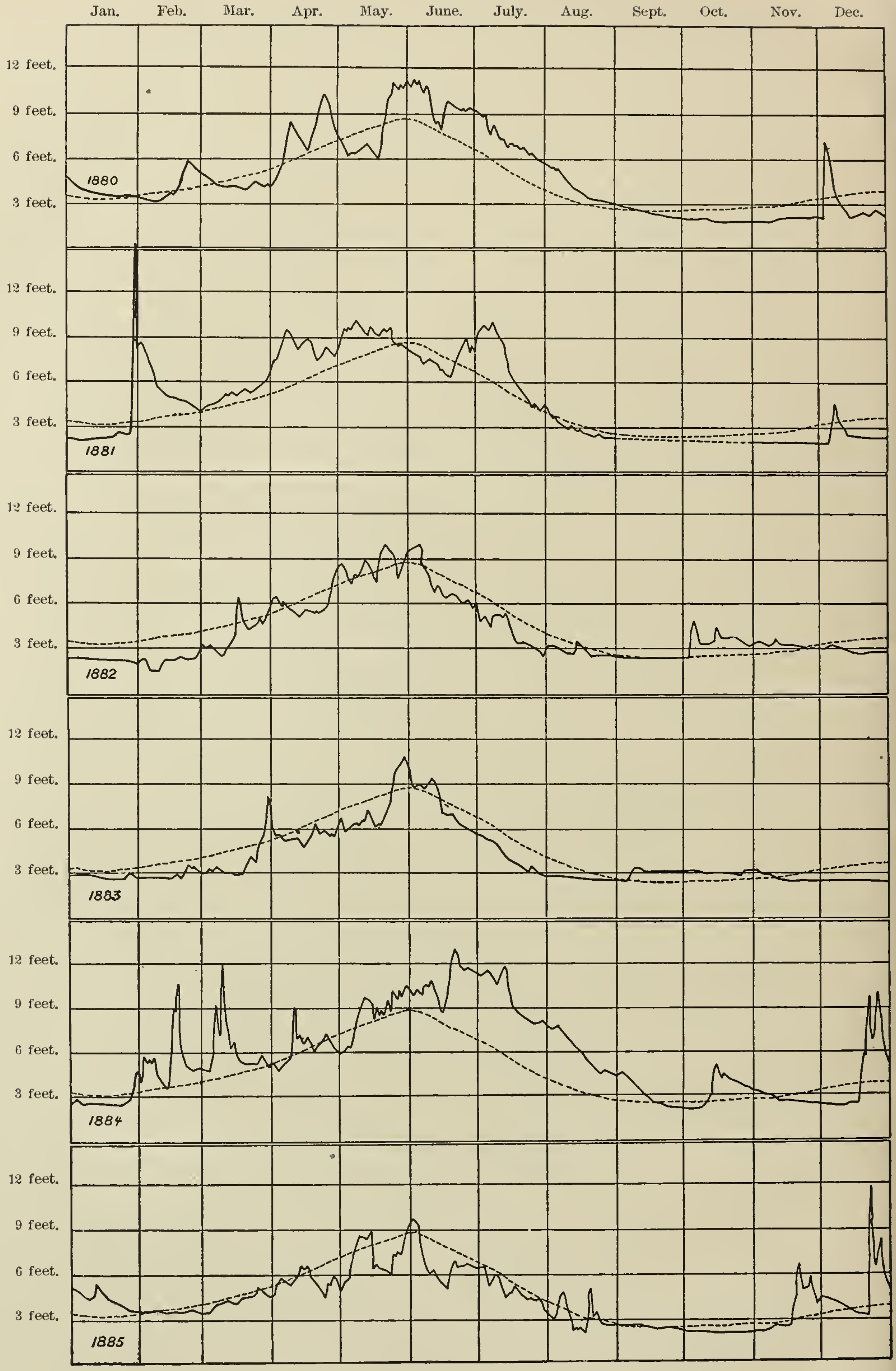
The Lower Gila District may be said to include the arable land from Gila Bend to Yuma, where the Gila River empties into the Colorado. This is a main-trunk district, receiving the waters which escape from the Middle Gila District and from the Lower Salt, and since these in turn receive their waters from four head-water districts, it will be recognized that the supply here depends very largely upon the action which is taken in these six subdivisions. There were only 555 acres on which crops were reported raised by irrigation in 1889, but a far greater acreage has been brought under ditch. There are a large number of extensive canals and ditch systems projected or under construction in this district, but whose success must apparently be a matter of some doubt.

The land of the Lower Gila District is of great fertility and is adapted to the cultivation of many fruits of the semitropic zone, as, for example, oranges, lemons, and other citrus fruits. It is thus known as the citrus belt of Arizona, and promises to become of great importance in these productions. Besides the fruit, alfalfa, barley, and wheat are reported to be cultivated, and vineyards have been successfully planted. The following canals were reported as built or under construction in 1889, to take water from the Gila in Maricopa County:

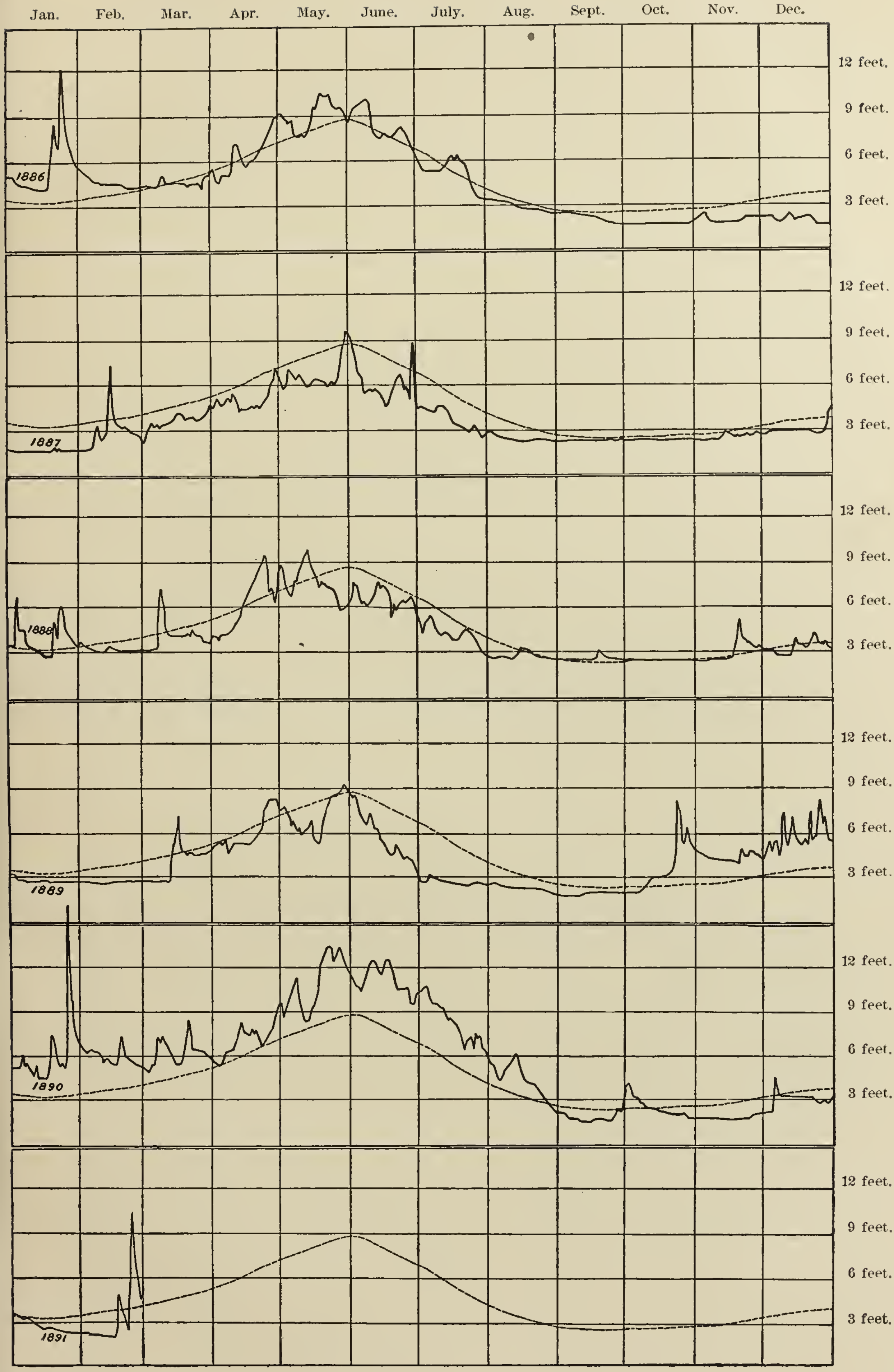
Canal.	Length.	Covers.	Canal.	Length.	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Buckeye	30	20,000	Citrus	14	5,000
Gila River	8	5,000	Monarch	8	2,000
Enterprise	12	6,000	Gila River Irrigating Co	12	....
Gould Bros	8	3,000	Gila Bend Canal Co	30	18,000
Palmer	22	12,000			

The Gila River Irrigating Company proposes to build a large dam at the Black Buttes below the mouth of the Hassayampa and carry water south and southwest, taking in the entire valley on both sides of the river to the Yuma County line, making a canal 75 miles long, covering 500,000 acres of land. The Gila Bend Company have completed 22 miles of their canal, under which 3,400 acres are reported to be irrigated at present. The names of the canals, together with their lengths and amount of land below each, taken from the Gila in Yuma County, as reported by the hydrographers, are given below:

Canal.	Length.	Covers.	Canal.	Length.	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Mohawk	35	40,000	Contera	7	2,000
Redondo	5	1,500	Saunders	10	4,000
Farmers	13	10,000	Araby	8½	2,000
South Gila	22	12,000	Antelope	7	2,500
Purdy	10	7,000	Toltec	3	....



GAUGE HEIGHT OF THE KINGS RIVER A



NGSBURG, CALIFORNIA, 1880 TO 1891.

THE AGUA FRIA AND HASSAYAMPA DISTRICTS.

The Agua Fria and Hassayampa districts lie south and west of the Verde Basin and between it and the Lower Gila District. The water supply of each is so small and the amount of arable land so large that they may each be considered as lost basins, although in time of large floods they may contribute to the Lower Gila.

The total area of the Agua Fria Basin to Gilette is 1,420 square miles. The supply of water, however, is not sufficient for all crops under cultivation, and in very dry seasons some are lost. The head waters of this district are in Yavapai County, where the principal industry is grazing, while the great portion of the arable land is south of this, in Maricopa County. The Agua Fria rises in the mountains southeast of Prescott and flows south as a clear mountain torrent, but as it enters the plains of the Gila the waters sink into the broad, sandy channel. In flood times, however, a great volume of muddy water is poured through the usually dry channel, entering the Gila a short distance below the mouth of the Salt River.

The Hassayampa District lies to the west of the Agua Fria, and, like it, has its headwaters in Yavapai County. Of the total area of 1,810 square miles in this district, about 937 square miles are in this county and 873 square miles in Maricopa County. In the headwaters of this basin was the Walnut Grove Dam, whose destruction in February, 1890, was the cause of considerable loss of life and property. On Pl. LXXVII is given a view of the reservoir formed by this dam. Hassayampa Creek, like the Agua Fria, is subject to violent freshets, whose waters reach the Gila, but at other times the stream sinks into the sands.

THE SANTA CRUZ DISTRICT.

The Santa Cruz District lies in the southern portion of the Gila Basin west of the San Pedro District. The limits of this district are extremely difficult to define, on account of the lack of good maps of the region. There are, however, approximately 3,500 square miles in this district, of which a small part of the head waters is in the Republic of Mexico and the remainder in the county of Pima, Arizona. The principal streams of this district are the Santa Cruz River and its tributaries, the Sonoita and Potrero. These creeks rise in the mountains of the south, where the elevation is from 4,000 to 5,000 feet, and join to flow northward as the Santa Cruz. The waters are finally lost in the sands not far from Tucson. In the upper part of the stream, among the rocky canyons and narrow valleys, is ample water, but in the lower portion of the stream there is, during the dry season, an amount insufficient to supply all the needs of the present acreage under cultivation, of which in all there was, in 1889, 2,672 acres.

In addition to the lost river basins before mentioned there are in the great drainage basin of the Gila areas aggregating 33,300 square miles, over which the rainfall either does not give rise to streams, or if little

streams are formed, they do not attain notable importance. Scattered through this region, much of it fertile land, are small localities where water can be brought from springs or pumped from saturated beds below the surface to irrigate small farms or gardens of stock-raisers. On the plains are many places where there is grass enough for herds of cattle if only water can be obtained sufficient for their needs. Deep wells have been sunk for this purpose, and large tanks for holding storm waters constructed, and occasionally there is obtained a surplus of water, by which a few plants are sustained. This method of irrigating will unquestionably spread gradually, but there is little to require the attention of others than those locally interested. The problems here are such that each man must solve his own for himself, and thus are in sharp distinction from the condition of affairs in the great districts above described, where the action of every man in his use of water has its influence, though slight, upon the prosperity of others.

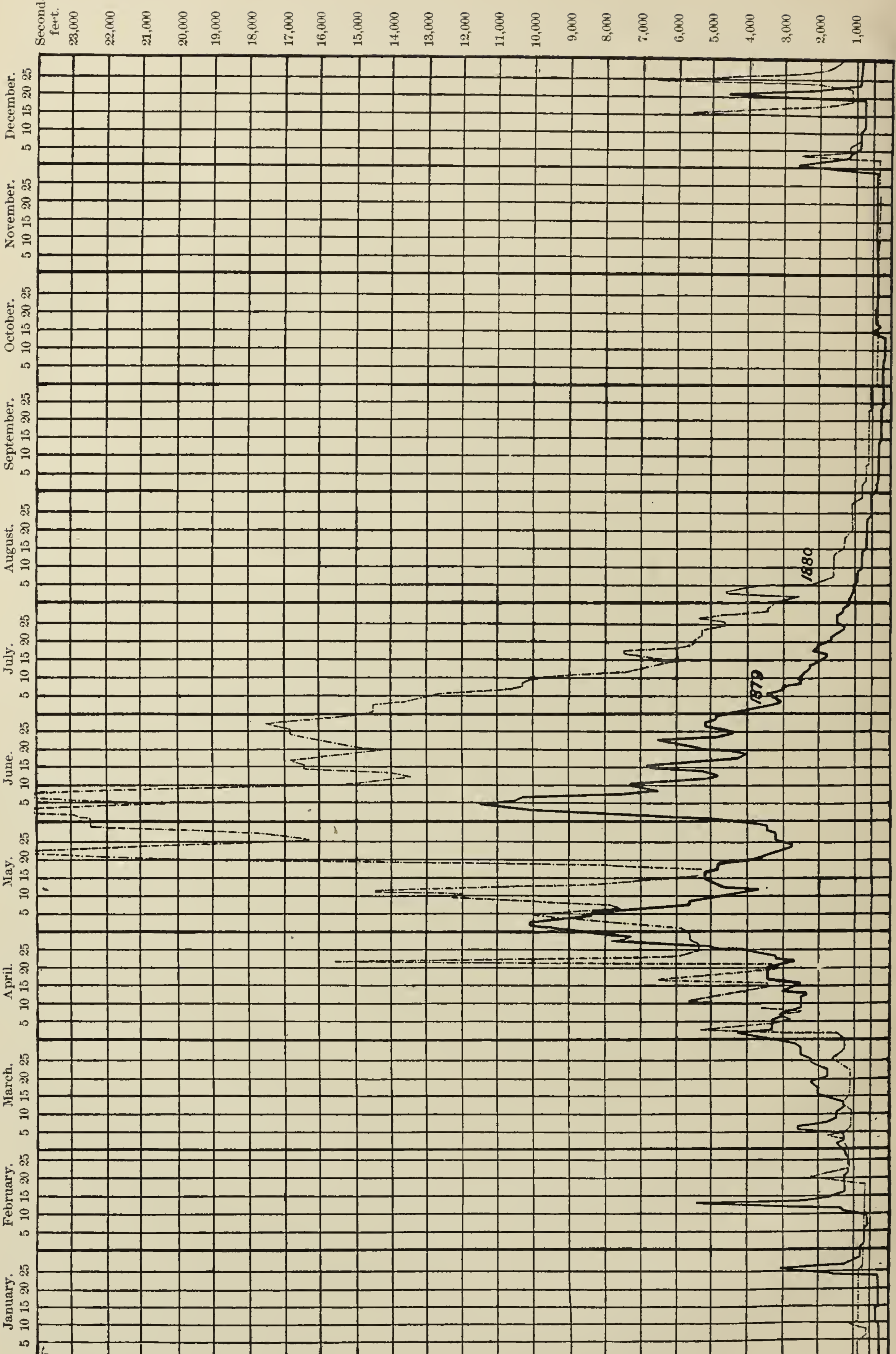
SACRAMENTO AND SAN JOAQUIN BASINS.

In these basins, lying wholly within the State of California, a careful examination of the water supply was begun in 1878 by the engineering department of that State, under the direction of its engineer, Mr. William Hammond Hall. Hydrographic measurements of an extensive character were begun and carried on successfully through several years, and a large amount of information bearing not only upon irrigation, but also upon the improvement of rivers, the flow of mining detritus, and drainage of swamp lands. At that time gauging stations were established, these being in many instances at or near railroad bridges crossing the streams, the height of the water being kept by employés of the railroad.

Many of the gauges established at that time have been kept in good order and read at regular intervals up to the present time. Credit is due to the officials, especially the chief engineer, of the Southern Pacific Company for the continuation of these gauge-height readings, whose value in connection with discussions of river flow is of the highest order.

In 1889 Mr. Hall, then supervising engineer for this Survey, began a series of measurements on certain rivers on which gauging stations had previously been established by the California State engineering department and the fluctuations of whose waters had been recorded by the railroad employés. The results, however, of these last attempts lie chiefly in the perfection of the methods to be employed on such streams and the devising of an apparatus for gauging from the shore, as described in the preceding annual report.

Briefly stated, the results of the river-gauging work of the State engineering department of California are as follows. The field work began in June, 1878, and during part of that and the succeeding year several parties were engaged in making gaugings of rivers and canals in connection with careful surveys for the purpose of acquiring facts


Second-feet.
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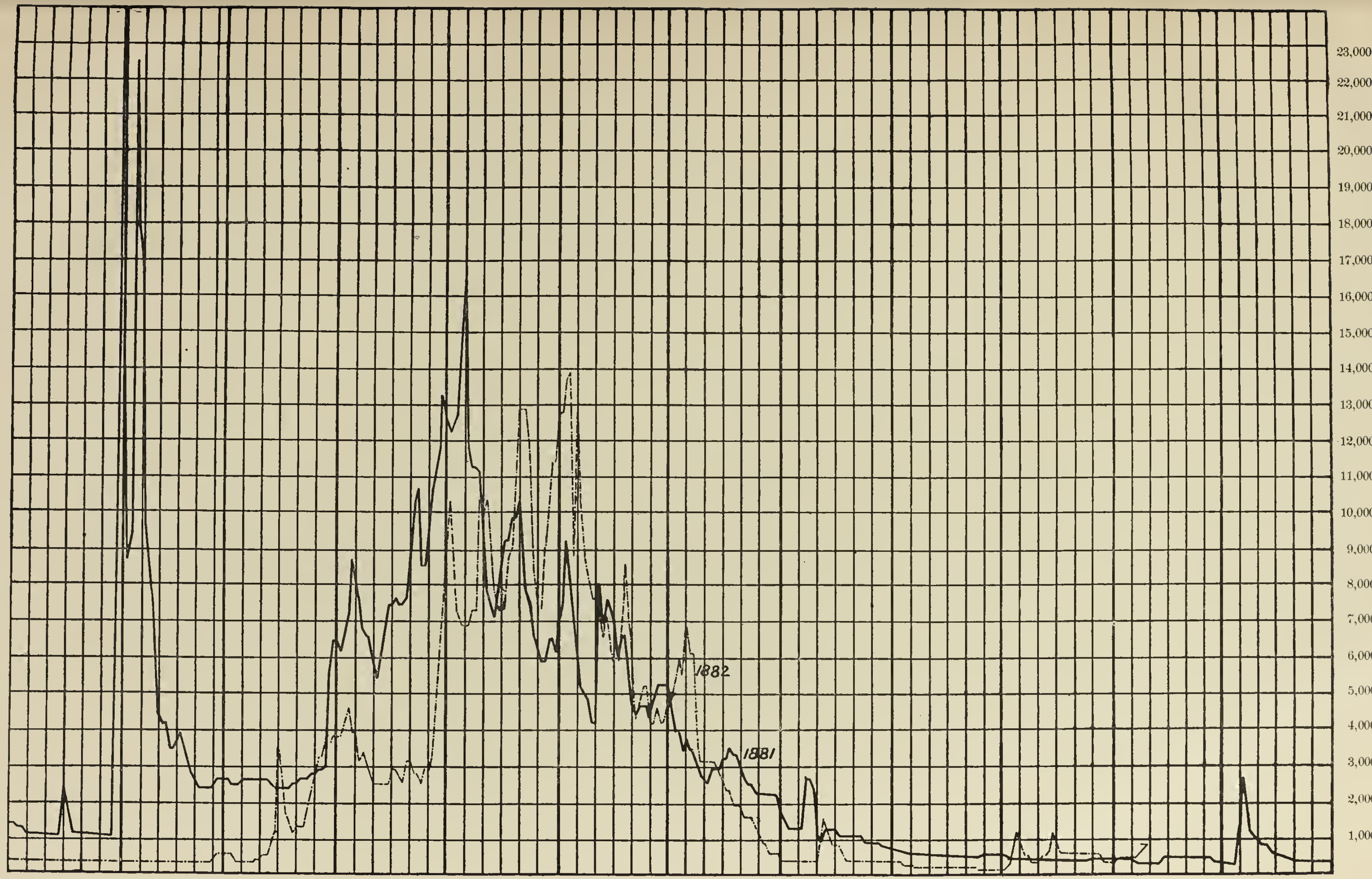
1879
1880



DAILY DISCHARGE OF THE SAN JOAQUIN RIVER AT HERNDON, CALIFORNIA, 1879 TO 1882.

bearing upon the solution of the problems of drainage, river improvement, mining detritus, and irrigation. Gauging surveys were made of the Sacramento at five places, viz, at Colusa, at Butte Slough, at Knight's Landing, at the mouth of the Feather River, and at the mouth of the American River, and also a survey of the American River itself.

At the same time a second party made gaugings of Kings, San Joaquin, Fresno, Chowchilla, Mariposa, Merced, Kaweah, and Tule Rivers. A third party examined the San Joaquin from the Stanislaus north, and a fourth party made gaugings up toward the headwaters of the Sacramento, namely on the Cosumnes, American, Bear, Yuba, Feather, and intermediate streams, as well as on the creeks northward to Chico Creek; also the Sacramento, both at Tehama and in the Iron Canyon, above Red Bluffs, and Stony Creek, besides all the other tributaries north of Stony and Chico Creeks. Observations of river height were maintained for a time on all the principal streams. There were in all, during the years 1878 and 1879, ninety-one gaugings made on rivers and two hundred and forty-three on canals, and there were established six self-registering tide gauges, one hundred and twenty-seven height rods or nilometers on rivers and fifty-two on canals.

The gaugings on large rivers were made mainly by current meters, but on the small streams and canals the discharge was computed by means of float observations or in some instances by Kutter's formulæ. In some cases careful surveys were made at each gnaging station extending for several miles, with cross sections every 400 feet, or with less care for 1 or 2 miles with cross sections at less intervals, down to a distance of one-half mile and sections every 200 feet. On the creeks and canals the general length of gauging survey was from 600 to 1,200 feet. All the rods and height gauges were connected by leveling, giving their relative elevation and the slope of the river from place to place.

In 1880 field work was continued, the gauging stations in the San Joaquin were put in repair and records collected; regaugings were also made of the Kern River and of the canals. In Los Angeles County in the summer thirty streams and ditches were gauged, and later in the season the discharge of eighty-eight small streams, ditches, artesian wells, etc., were obtained by making one hundred and eighty-three gaugings. At about the same time the low-water discharge of the streams flowing into the San Bernardino Valley was estimated by means of twenty-three guagings. This practically ended the field operations of the State engineering department as far as hydrographic work was concerned.

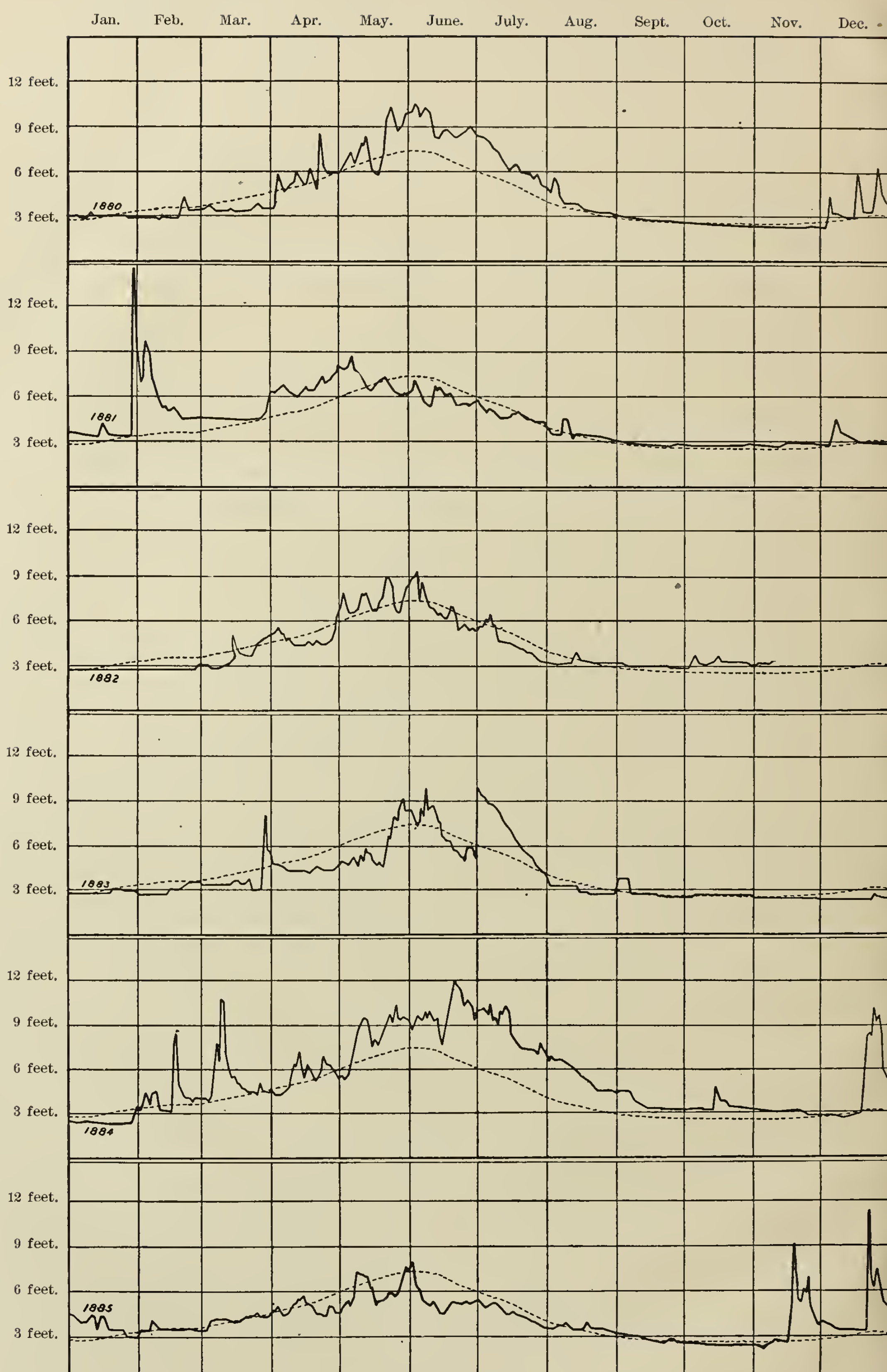
From the data obtained in the field computations of discharge were made for most of the rivers mentioned above, and the results of the gaugings and computations were published in 1886 in a volume entitled "Physical Data and Statistics of California," in which are given for each month and season, from November, 1878, to October, 1885, the maximum, minimum, mean, and total discharge in second-feet, together

with, in most cases, the depth of water drained and the amount drained per square mile from the basins of the following rivers, viz:

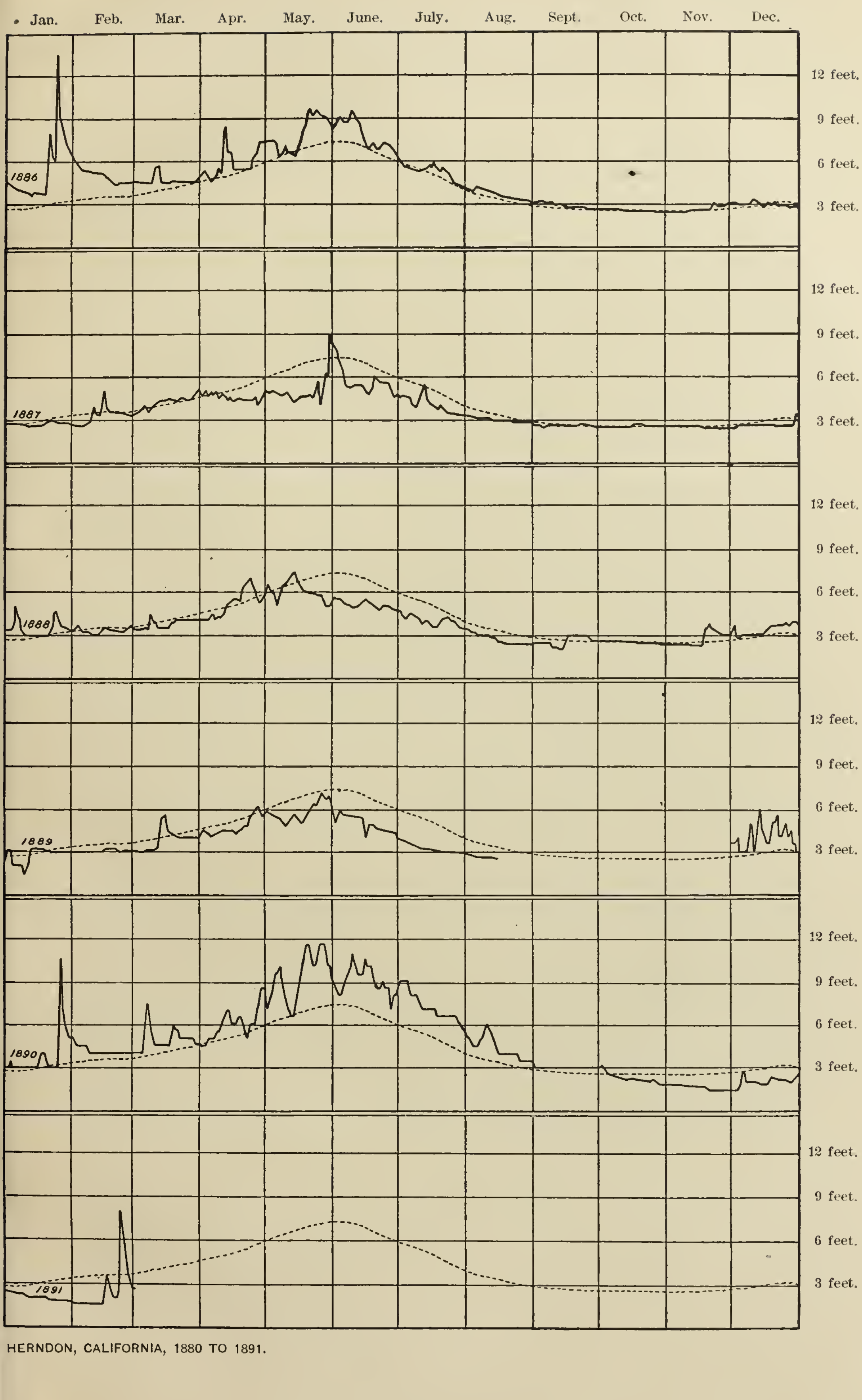
Sacramento River, at Collinsville.
Cosumnes River, at Live Oak Suspension Bridge.
Dry Creek, at base of foothills.
Mokelumne River, at Lone Star Mill (base of foothills).
Calaveras River, at Bellota.
Stanislaus River, at Oakdale.
Tuolumne River, at Modesto.
Merced River, at Merced Falls.
Bear Creek, at base of foothills.
Mariposa Creek, at base of foothills.
Chowchilla Creek, at base of foothills.
Fresno Creek, at base of foothills.
San Joaquin River, at Hamptonville.
Kings River, at Slate Point (base of foothills).
Kaweah River, at Wachumna Hill.
Tule River, at Porterville.
Deer Creek, at base of foothills.
White Creek, at base of foothills.
Poso Creek, at base of foothills.
Kern River, at Rio Bravo Ranch.
Caliente Creek, at base of foothills.

The information obtained from the State engineering department of California and from the Southern Pacific Company relating to the gauge height and discharge of the rivers in this basin is presented herewith on Pls. LXXX to LXXXVIII, in order to afford an opportunity of comparing the behavior of these streams with those in other parts of the arid region. These plates are arranged in geographic order, following the rule elsewhere laid down of taking the tributary streams in succession from the headwaters to the mouth. The headwaters of the San Joaquin, being nearest the Colorado Basin, are first presented.

In the cases of many important streams, the height of whose waters has been recorded for a series of years, the relation between the discharge and height has not as yet been obtained. Although our knowledge would be far more complete if the daily discharge were known, yet the range of height of the river for a long period gives many facts of importance and is of sufficient value to justify the representation of these fluctuations. The curve of average height for all the years during which gauge readings were made is placed on these diagrams. This may be considered the normal curve for the river, and when placed in connection with the actual fluctuations of the stream each year, the abnormal variations of that year are at once apparent. In looking over these plates it will be seen, for example, that on some years the height remains persistently below the normal, while on others it is above, and still on others varies widely in both directions. As a matter of course no year follows exactly the normal or average curve.



GAUGE HEIGHT OF THE SAN JOAQUIN RIV



HERNDON, CALIFORNIA, 1880 TO 1891.

KERN RIVER.

Kern River is the largest stream in the southern end of the San Joaquin Valley, draining a large area in the mountains west of the main range of the Sierra Nevada. This stream has been ganged at the Rio Bravo Ranch, just below the point where the river leaves the canyons and above the irrigating canals, this locality being about 12 miles from Bakersfield. The record of river heights was kept for 1879, 1880, 1881, and 1882, and daily mean discharges, shown graphically on Pl. LXXX, were computed for these years. By referring to this plate the wide range in annual discharge is seen, and also the characteristic irregular fluctuations.

In 1879 there was apparently no spring flood, but in place of this almost continuous low water, broken only by slight fluctuation, as represented on the diagram by the dotted line. In 1880, on the other hand, the discharge, shown by the fine black line, reached the maximum of 4,070 second-feet in June, and the flood as a whole was large and persistent, being preceded by a sharp rise on April 3 and extending to the end of July. The high water of 1880 continues into 1881, as shown by the line consisting of dots and dashes. This flood, however, did not reach the height of that of the previous year, but attained its maximum early in May, and then with minor fluctuations fell rapidly through June and July.

In 1882 the discharge, as indicated by the heavy black line, was intermediate between those of previous years, coinciding in winter and late summer fairly well with the discharges of 1879 and 1880. In addition to these, the mean discharges for 1883 and 1884 have been published in the Physical Data and Statistics of California, having been computed by using the rainfall measurements of these years as a basis and assuming a certain relation between these and the river flow.

TULE RIVER.

The drainage area of this river lies west of the head waters of the Kern, the main stream flowing directly westward and emptying in time of floods into Tulare Lake. At other times the water is all used for

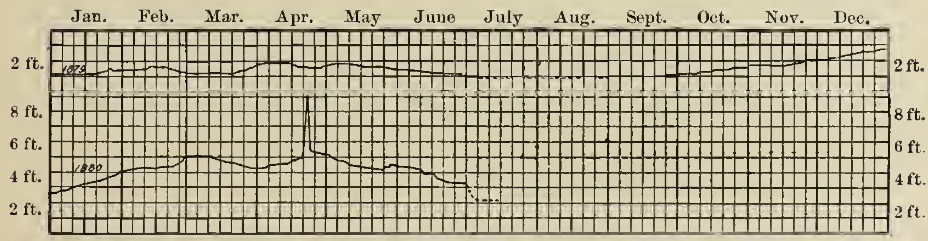


FIG. 227.—Diagram of daily gauge height of the Tule River, California.

purposes of irrigation from Porterville to Tipton. Measurements were made about 5 miles above Porterville, but below the head of the Pioneer Canal. The gauge height only for this stream is shown on Fig. 227, for

the greater part of 1879 and the spring of 1880. This fragmentary record serves to give in a general way the character of the stream during those years. In the early part of 1879 the water, as in the case of the Kern River, was extremely low, and the flood rise is scarcely apparent. At the beginning of the succeeding winter, however, the water began to rise and continued until April, when there was a slight fall, succeeded in the latter part of May by a sudden flood, the effect of this flood being felt far into the summer.

The mean monthly discharge of this river for these and the succeeding years up to and including 1884 has been published,[1] and also the mean discharges for the same period of the adjoining creeks, the Deer, White, and Poso.

KAWEAH RIVER.

The Kaweah drainage area lies between that of Tule River and of Kings River. The river enters the San Joaquin Valley northeast of Tulare Lake and furnishes water for large areas in the vicinity of Visalia. Discharge measurments were made principally in the vicinity of Three Rivers, being thus in the mountains above some of the smaller tributaries. The discharges for 1879, parts of 1880, 1881, and 1882 are shown on Pl. LXXXI.

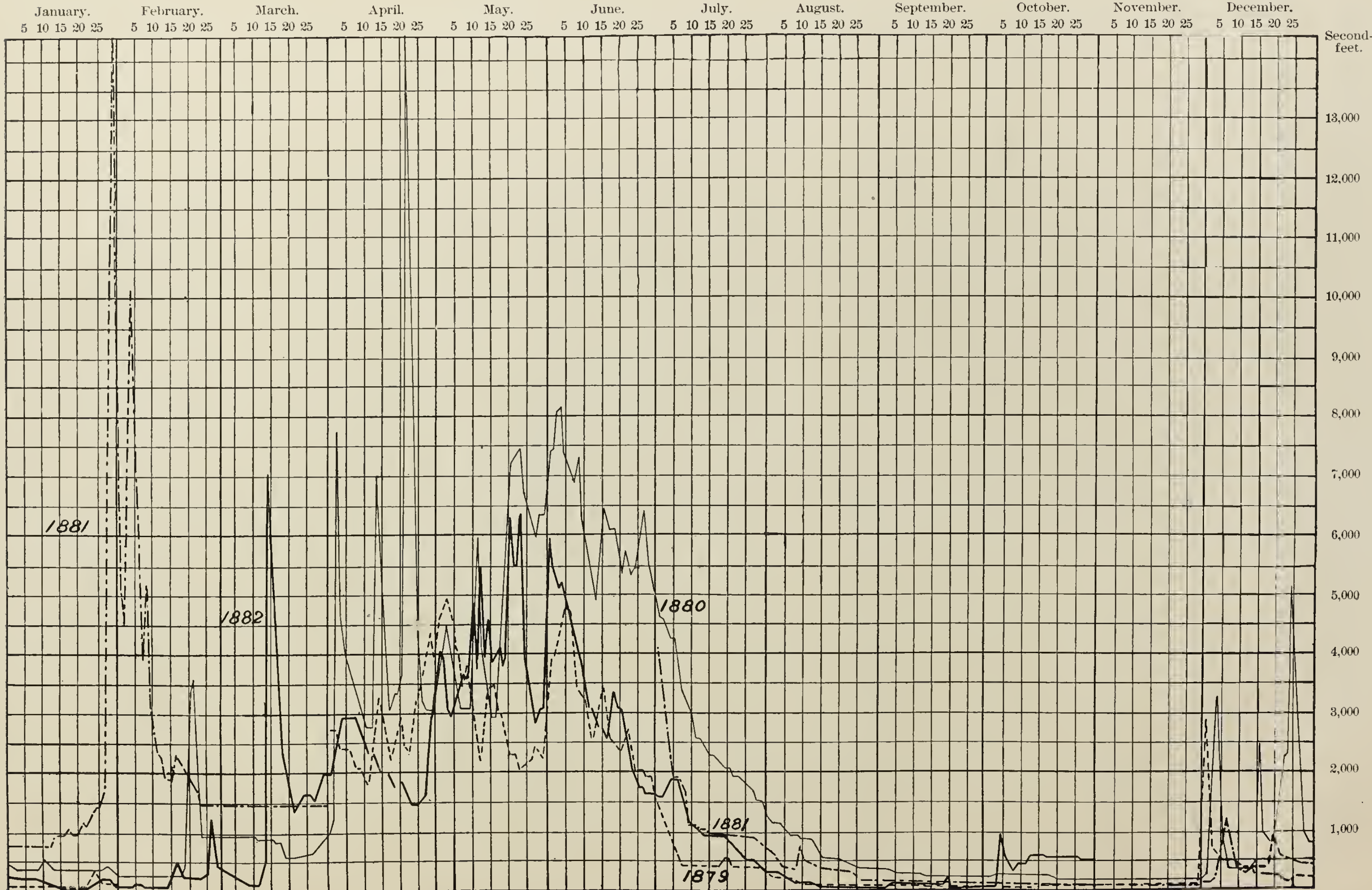
The discharge for 1879, as in the case of the rivers above mentioned, was very small, but in 1880 heavy floods occurred, some of which, as for example that of April 20, were of unusual violence. The record from July 1, 1880, to June 30, 1881, has not been preserved, but the fall and winter of 1881 are shown and the spring of 1882, the discharge for this latter period being indicated by a heavy black line.

KINGS RIVER.

The State engineers found this important river exceedingly difficult to measure, on account of the shifting character of its bed and banks or of other obstacles. Gaugings, however, were made by them at various points, by means of which they were enabled to make computations of the discharges from 1879 to 1884, inclusive. One of the most important factors in this computation was the record of gauge height kept at the Southern Pacific Company's bridge near Kingsburg. This record, which has been maintained up to the present time, is given on Pl. LXXXII, in connection with the curve of average river height for the entire period.

This diagram exhibits the relative height of the river in each year and the time of occurrence and extent of the floods, as, for instance, in the years 1880 and 1881 the water in general was above the average, while in 1882 and 1883 the spring floods did not reach their usual height. In 1884 the flood was large, and especially notable from the fact that

[1] Physical data and statistics of California, collected and compiled by the State engineering department of California, William Ham. Hall, State engineer, Sacramento, State printing office, 1886, pp. 459, 460.



DAILY DISCHARGE OF THE MERCED RIVER AT CENTRAL PACIFIC RAILROAD BRIDGE, CALIFORNIA, 1879 TO 1882.

it occurred late in the season, a great part coming in July. During the year following the water remained low, and in 1886 was a trifle above the normal. The years 1887, 1888, and 1889 were similar in character as regards the small size of the floods, while 1890 rivaled 1884 for the extent of high water.

SAN JOAQUIN RIVER.

The San Joaquin was gauged both at the edge of the valley and at the Southern Pacific Railroad crossing, near Sycamore, now Herndon, the record at this lower point, however, being the most extended, having been kept by the Southern Pacific Company continuously to the present year. The discharge for this place for the years 1879, 1880, 1881, and 1882 is shown on Pl. LXXXIII. On account of the peculiar irregular character of these discharges, they are represented in two groups, 1879 and 1880 being placed together, and also 1881 and 1882 by themselves, since the lines for these last two years would fall intermediate between those for the preceding two years.

Low water for 1879 and high floods in 1880 are shown to have characterized this river as well as those farther south. The sudden flood of February 1, 1881, almost equaling those of May and June of the preceding year, is notable as showing the irregularity in time of these freshets. It is interesting to compare these lines with those representing the discharges of rivers in Colorado, Utah, and Montana, where the floods are more gradual and do not as a rule occur with such violence. It is to be noted that these sharp irregular fluctuations are due to changes of temperature rather than to rainfall, most of the floods being caused by the melting of the snow among the mountain summits, the effect of the flood being of course intensified by warm rains, if these occur.

The mean monthly discharge for these years and for 1883 and 1884 has been computed by the California engineers, and could probably be estimated up to the present time from the gauge readings kept at Herndon. The gauge heights themselves are, however, given on Pl. LXXXIV for direct comparison among themselves. The heavy flood of 1880 is apparent by the position of the black line above the dotted, and the smaller floods of 1881 and 1882 can also be seen. In 1884 the flood was the greatest recorded both in amount and duration, as was the case in the Colorado basin, as previously noted. The year 1885 was noted by the continuance of the river height for long periods below the normal, and 1886 by an equal persistency above the normal. In 1887, 1888, and 1889 the river continued at low stages, but in 1890 rose again to heights unknown since 1884, falling off in the winter, the beginning of 1891 being marked by unusually low water.

By comparing diagrams of discharge for 1880, 1881, and 1882 with those of gauge height for the same period, the difference between these two classes of graphic illustrations is apparent. As the water rises a

greater and greater amount flows in the stream for every increase in height. The diagram of discharge is so drawn that the vertical spaces represent equal quantities of water, while in the gauge height diagrams the vertical distances represent heights of water without regard to quantity. Thus the two diagrams show the same fluctuations on the same days. The lower parts of both diagrams are very nearly alike, since at low stages the discharge increases very nearly with the additional height, but the upper part of the discharge diagram in comparison with that of gauge height appears as though stretched out in a vertical direction, from the fact that the quantity discharged at the high stages is increasing rapidly.

MERCED RIVER.

The discharges for this river at the gauging station near the railroad bridge between Delhi and Livingston are given on Pl. LXXXV for the years 1879, 1880, 1881, and 1882. As shown by the diagram, these discharges show great irregularities, but during May fall within a comparatively small range. The early floods of the year are particularly noticeable for their intensity, as, for instance, that of 1881.

TUOLUMNE RIVER.

The Tuolumne is one of the most important rivers in the northern part of the San Joaquin Valley. It flows nearly due west from the

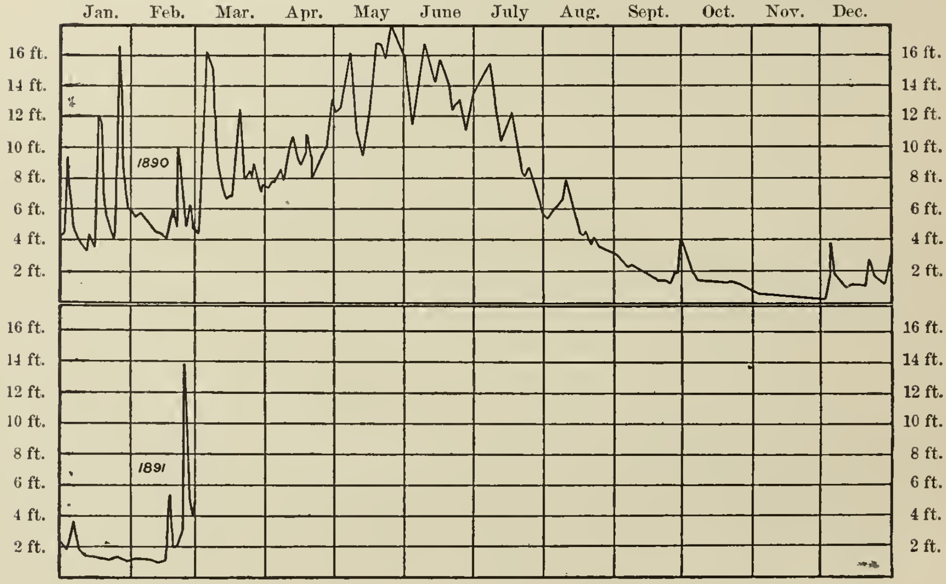
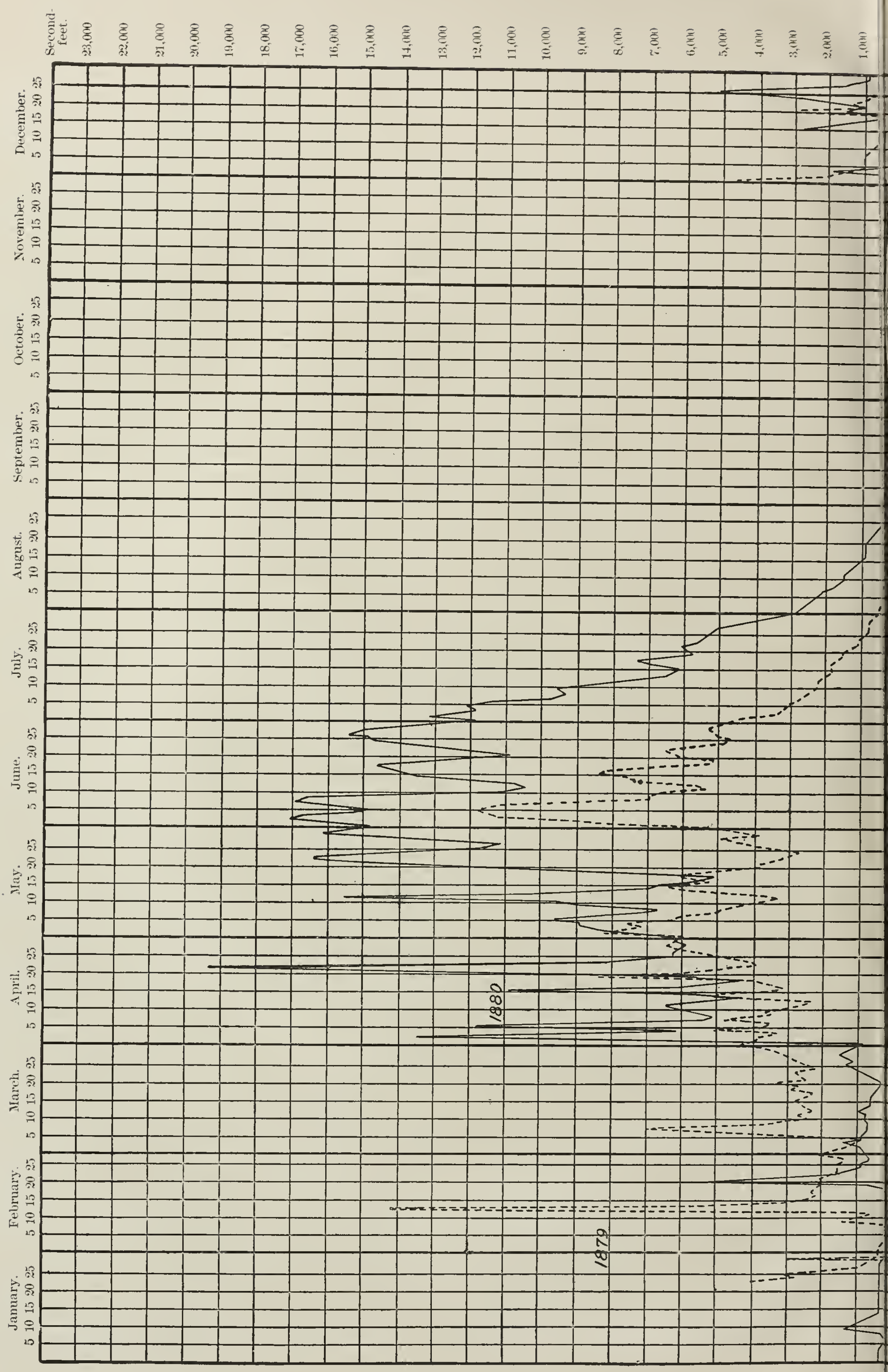
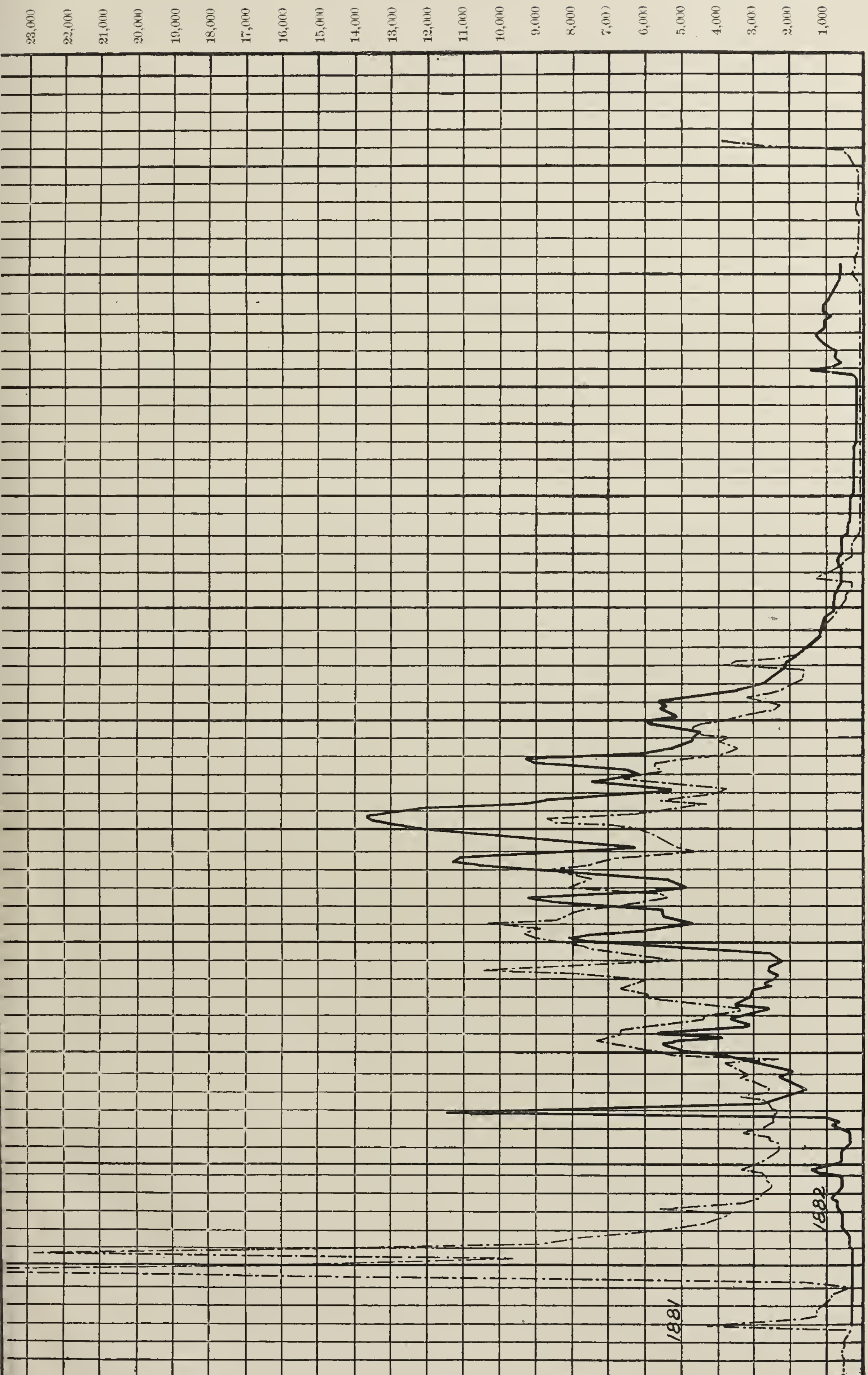


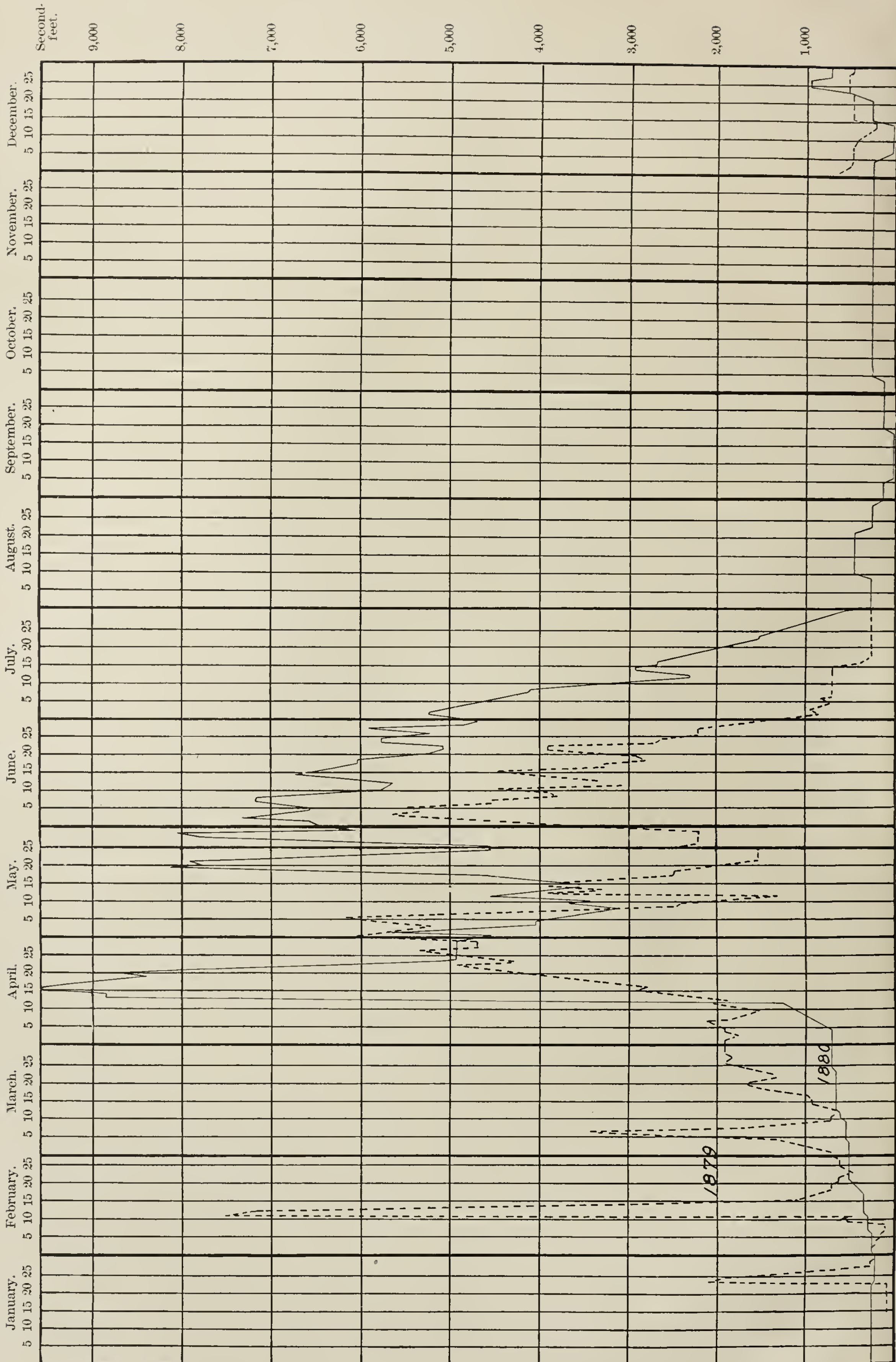
FIG. 228.—Diagram of the daily gauge height of the Tuolumne River, California, 1890 and 1891.

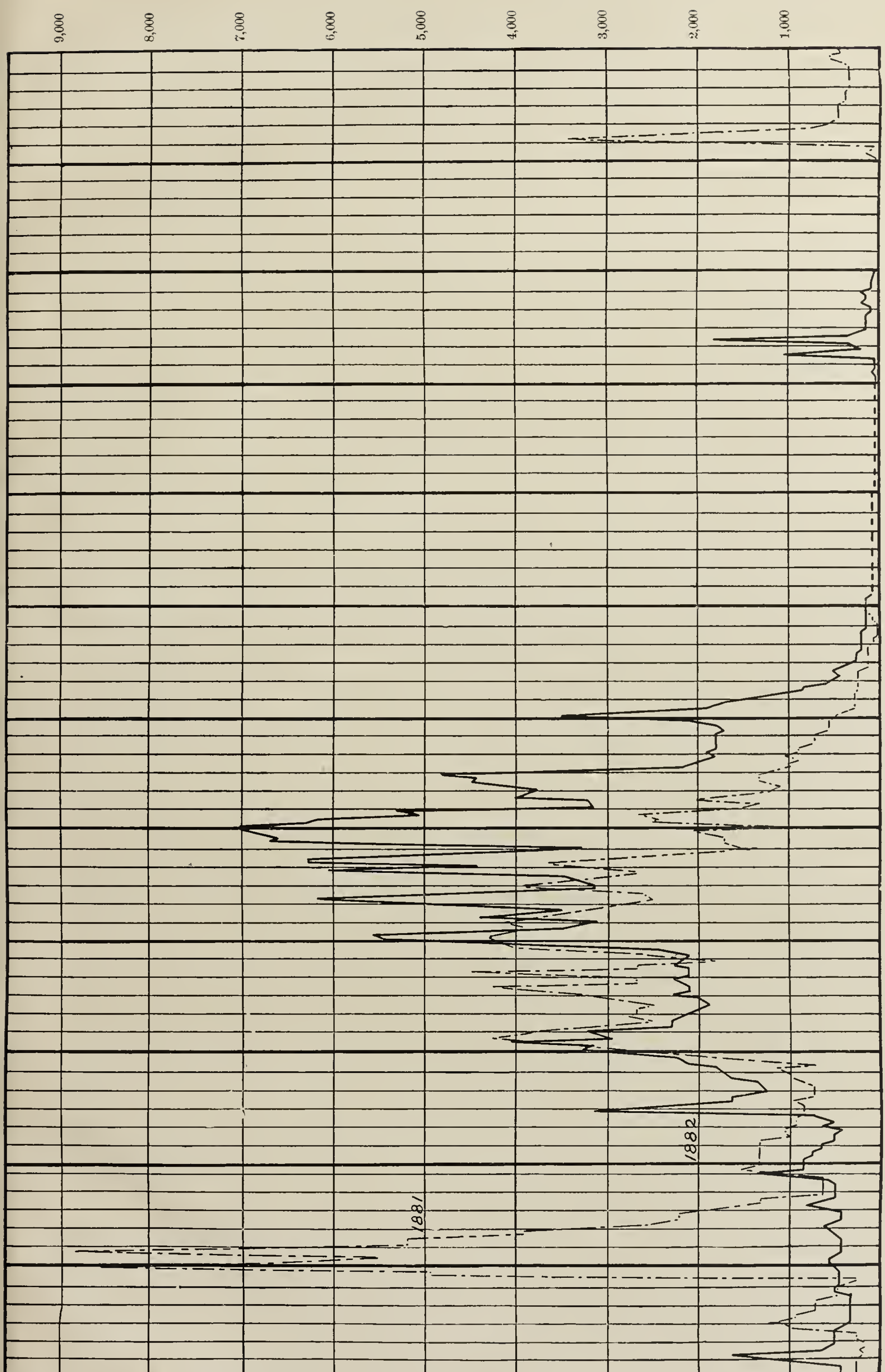
Sierra Nevada, the waters being used for irrigation in the vicinity of Modesto. The gaugings of this river were made near the railroad bridge


Second-feet.
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
January. 5 10 15 20 25
February. 5 10 15 20 25
March. 5 10 15 20 25
April. 5 10 15 20 25
May. 5 10 15 20 25
June. 5 10 15 20 25
July. 5 10 15 20 25
August. 5 10 15 20 25
September. 5 10 15 20 25
October. 5 10 15 20 25
November. 5 10 15 20 25
December. 5 10 15 20 25
1880
1879



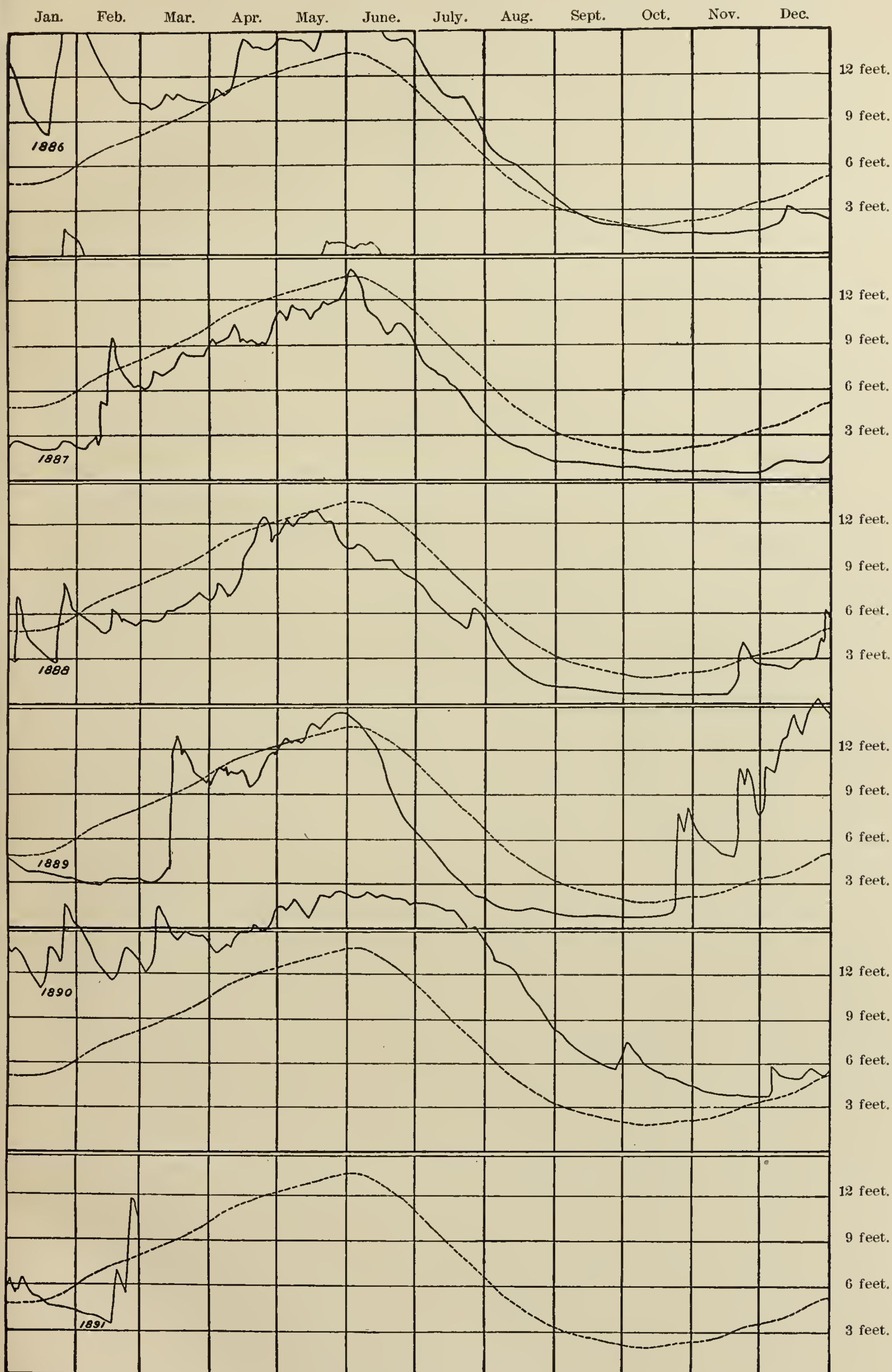
DAILY DISCHARGE OF THE TUOLUMNE RIVER AT MODESTO, CALIFORNIA, 1879 TO 1882.


Second-feet.
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
January.
February.
March.
April.
May.
June.
July.
August.
September.
October.
November.
December.
1879
1880



DAILY DISCHARGE OF THE MOKELUMNE RIVER AT MAGEE'S MILL, CALIFORNIA, 1879 TO 1882.

GAUGE HEIGHT OF THE LOWER SAN JOAQUIN RIVER AT C



RAL PACIFIC RAILROAD BRIDGE, CALIFORNIA, 1880 TO 1891.

south of the town, the record being kept for many years by the railroad company. The discharges are shown on Pl. LXXXVI, those for 1879 and 1880 on the upper half of the page, and for 1881 and 1882 on the lower half. The discharges of these years show the characteristic fluctuations, 1879 being low, 1880 high, and 1881 and 1882 in general intermediate.

The daily gauge height of this river for 1890, and a part of 1891, is shown on Fig. 228, the discharges not having been computed. This serves, however, to show the relative fluctuations during the various months of these years and the irregularity in the character of the stream.

MOKELUMNE RIVER.

The Mokelumne River enters the Sacramento Valley at about one-third of the distance from Stockton to Sacramento. It is considered a tributary of the San Joaquin, for although flowing toward the Sacramento, when within about 2 miles of that river its waters turn abruptly toward the south. The flow was measured on the edge of the valley above Clements, giving the discharges shown on Pl. LXXXVII. In this case, as in that of previous rivers, 1879 and 1880 are shown together on the upper half of the page, and 1881 and 1882 on the lower half. The difference in discharge between 1879 and 1880 is not as strongly marked as in the case of the rivers farther south, and when the discharges for the four years are plotted on the same sheet the result is a confused mass in which no one year is particularly prominent for the quantity of its discharge.

The excessive floods of early spring, as in 1879 and particularly in 1881, are the most noticeable features of these diagrams. The rapid fluctuations in quantity, so characteristic of the streams of this basin, are exhibited on this river. The culmination of the floods in the latter part of May and their gradual decline in June is clearly shown.

LOWER SAN JOAQUIN RIVER.

The height of the San Joaquin has been observed for a number of years by the Southern Pacific Company at its bridge. These daily gauge heights have been plotted, and are shown in condensed form on Pl. LXXXVIII, giving the fluctuations in height from 1880 to the present time. The average height of the river for each day in the year during the series of years through which observations were made is indicated by the dotted line, the irregular line showing the daily variations in each year from this average. In examining these in detail it will be seen that the flood of 1884 is, as in other cases, far above the normal.

In the diagram for 1886, at the top of the plate the discharges for floods in January and May, are so great as to bring the line above the upper margin of the plate. The amount by which this line overruns is shown by the dotted lines immediately below these places. In 1887, 1888, and 1889, the height is in general below the average, but in the fall of the latter year the water rose suddenly and continued at an un-

precedented height during that winter, the volume during each month almost equaling that of the flood discharge of May or June. This great flood continued through July, and then declined, reaching the normal at the end of the year, the beginning of 1891 being marked by low water.

THE GREAT BASIN.

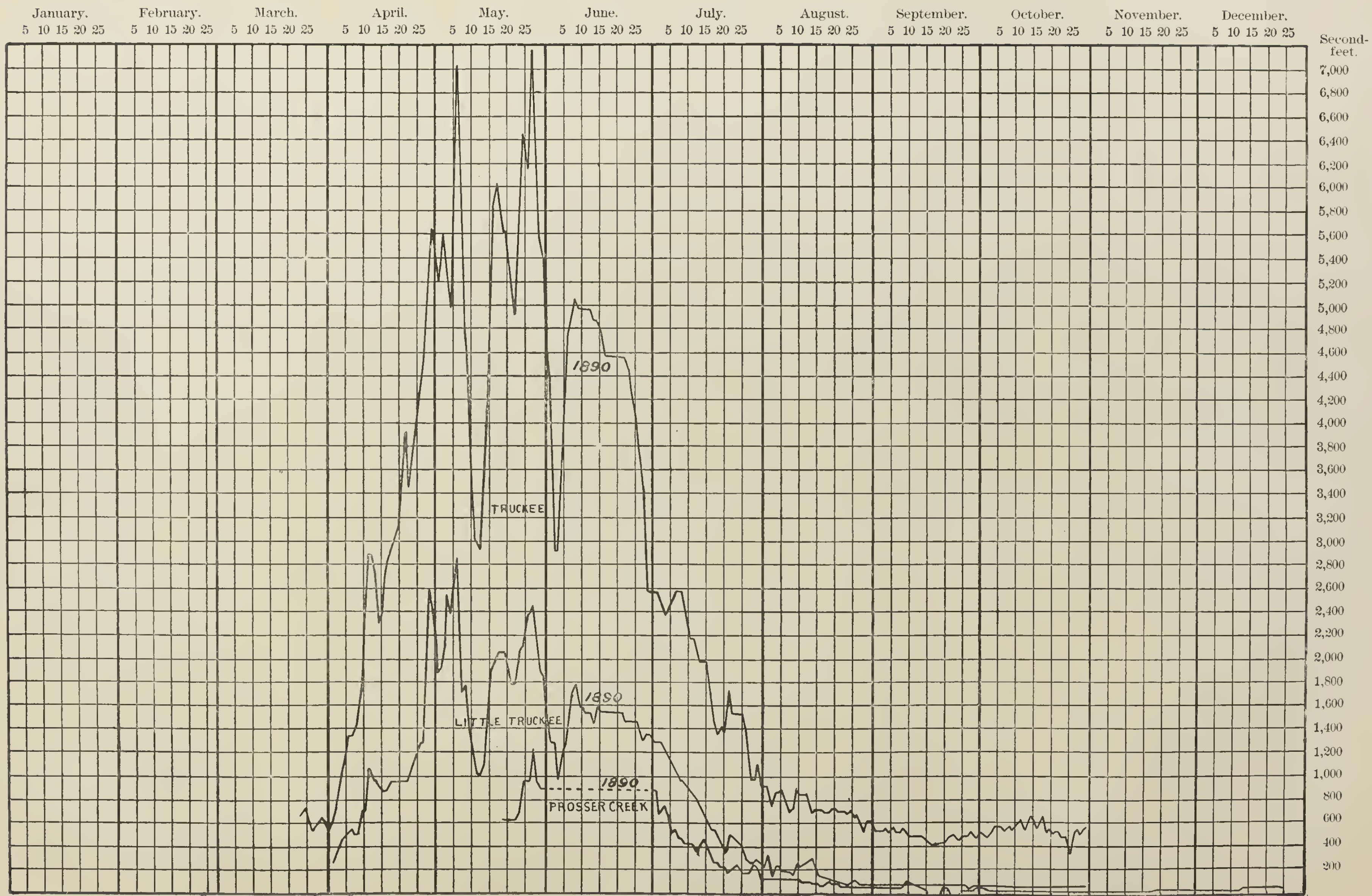
This term is applied to that vast extent of country lying between the Rocky Mountains and the Sierra Nevada, and embracing an area of 228,150 square miles, from which no water escapes to the ocean. The rain which falls within this area collects in the streams, and these in turn unite, forming large rivers in certain parts of the basin; but in spite of their size they are destined sooner or later to disappear, either by evaporation from their broad sandy channels or from the surface of some saline lake. The larger rivers are on the extreme eastern or western sides of this basin, for it is here only that lofty and continuous ranges of mountains are found. On the north the divide between the drainage of the Columbia is not sharply defined by great mountains, nor is it on the south adjoining the Colorado.

Stream measurements have been made by the Geological Survey on the principal streams on both sides of the Great Basin. On the western edge the Truckee, the principal river of the Pyramid Lake drainage basin, has been measured in several places, and also the Carson, whose waters disappear in Carson Sink. On the eastern edge of the Great Basin, in the Salt Lake Basin, measurements have been of the principal streams, the Bear, Weber, Provo, and others, and in the Sevier Basin of the Sevier River mainly at the point where it enters the Sevier Desert. The results of these measurements are given in the following pages in the order stated. The gauging stations have been described in the preceding annual report of this Survey. In the case of the Bear and Sevier rivers a somewhat detailed description of the topography is given, in so far as it relates to the questions of water supply and irrigation.

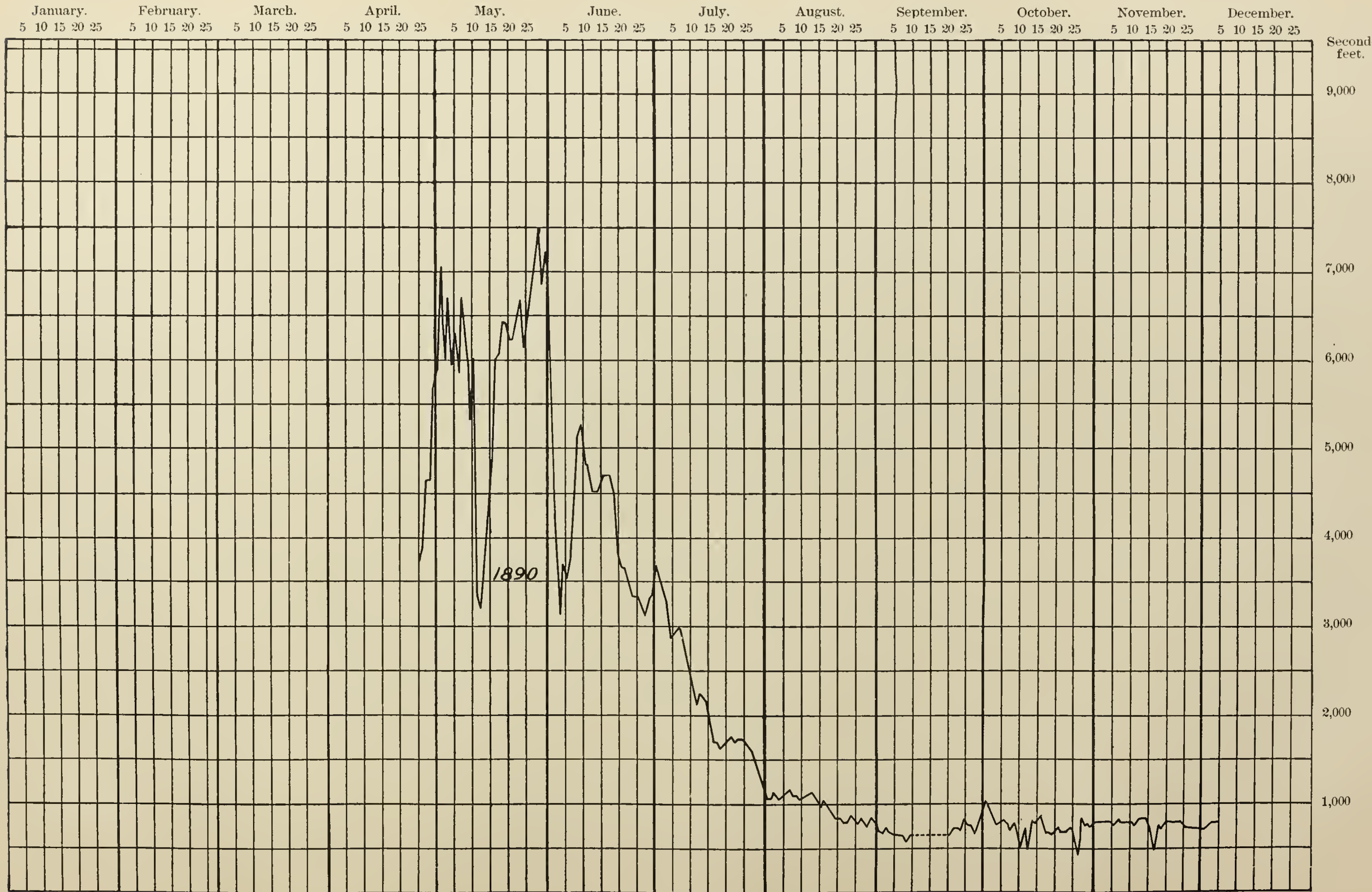
TRUCKEE RIVER.

On Pl. LXXXIX is shown the discharge for the greater part of 1890 of Prosser Creek, the Little Truckee, and the Truckee below Boca, California. Prosser Creek and the Little Truckee flow into the Truckee a short distance above this town, and consequently the discharge below Boca includes that of these two streams. As might be expected, these discharges follow each other closely, since, the drainage basins being small, similar climatic conditions prevail over all.

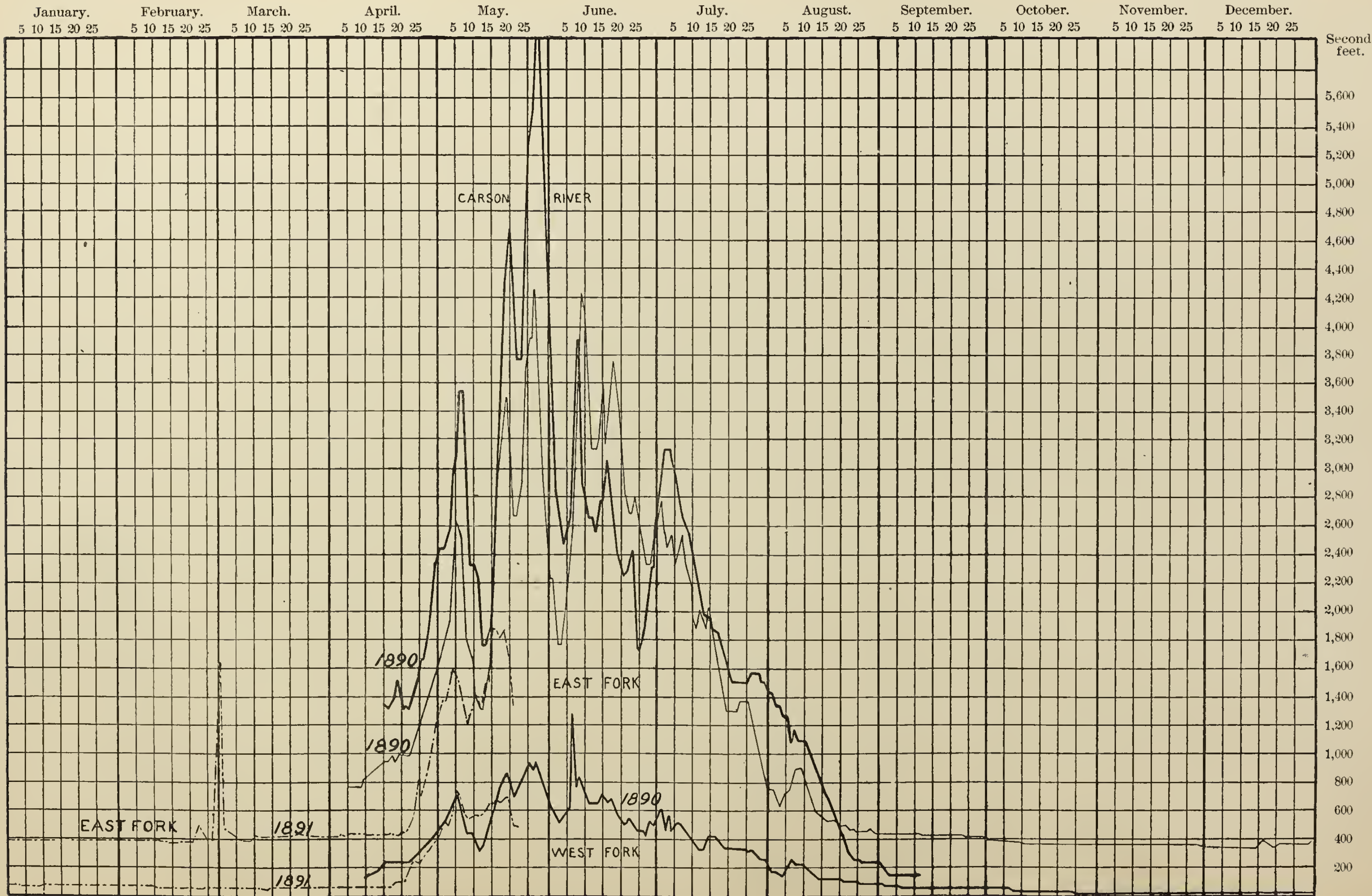
Measurements were made of the Truckee at two points farther down the river—one at Laughtons, about 6 miles above Reno, and the other at Vista railroad station, about 8 miles below Reno, at the lower end of the Truckee meadows. The discharge at these two points follow each other so closely that a single illustration is sufficient. Pl. XC shows



DAILY DISCHARGE OF PROSSER CREEK, LITTLE TRUCKEE, AND TRUCKEE AT BOCA, CALIFORNIA.



DAILY DISCHARGE OF THE TRUCKEE RIVER AT VISTA, NEVADA.



DAILY DISCHARGE OF THE CARSON RIVER NEAR EMPIRE, NEVADA, AND EAST AND WEST FORKS OF THE CARSON.

the quantity of water discharged during all but the early months of 1890, and by comparing this with Pl. LXXXIX the similarity is shown between the behavior of the river at Boca and at Vista.

CARSON RIVER.

The discharge of the main Carson, 5 miles east of Carson City, near Empire, Nevada, for 1890, is shown on Pl. XCI, in connection with the discharges of the East and West forks. The station at Empire was abandoned in the fall of 1890, but daily readings of gauge height for the East and West forks have been received to June, 1891, thus allowing computations of discharges to be made up to that time. In this diagram the large amount of water received from the East Fork is a prominent feature, the discharge of the West Fork being relatively small. It is apparent from the diagram that the discharge of the main river is in many cases, especially in the latter part of August and in September, less than the total of the two forks, this being due to the large diversions of water for irrigation made from these streams in the valleys through which they flow.

SALT LAKE BASIN.

BEAR RIVER.

The headwaters of this river, as shown by the map (Pl. XCII), are in the high peaks about 60 miles east of Salt Lake City. Here, at an elevation of from 9,000 to 11,000 feet, are small glacial lakes and basins which originally held a large amount of water, but by erosion the lower rims have been cut, allowing this water to escape. The torrential streams from these glacial lakes flow down the highly inclined slopes, and unite in the deep, narrow valleys at the foot of the peaks. Most of these valleys consist of alternations of narrow passes and broader meadow lands, where the streams become almost stagnant and meander through small marshes. At the lower end of each of these open spaces a dam could be built at small expense, all the materials being close at hand, making ponds from a quarter to a half mile in width and 1 mile or even more in length. These valleys have all the advantages of reservoir sites, the only objections to their use being the great distance which the stored water must travel before reaching altitudes sufficiently low to mature the more valuable crops.

The water flowing northward from these valleys crosses the line between Utah and Wyoming and entering the latter State continues in the same general northerly direction, passing through rolling pasture lands. These lands are too high for agriculture, but are adapted to grazing, and along the course of the streams are many ranches at which forage is raised as winter feed for cattle. Diversions of the waters of the Upper Bear and its tributaries are made at intervals in this high country, but the ditches are small. At Evanston, however, several

canals of notable size take water from the Bear River to supply the town and adjacent hay lands.

Northward from Evanston, in Wyoming, the valley continues open, the stream falls rapidly, and at short intervals ditches are taken out, the water being used mainly for the purpose of raising hay. Most of the tributaries which enter the Bear in this portion of its course have large drainage areas, but these consist for the greater part of gently rolling hills, and do not in ordinary seasons contribute perennial streams. The snow which falls upon these hills evaporates to a large extent without melting, there being few gulches or ravines into which it can drift and pack. The rainfall also upon these gentle slopes does not usually gather into large streams. On the other hand, in the case of exceptional storms, coming with such rapidity that they can not saturate the ground, large bodies of rain water flood these rolling lands and cause torrents in the ravines. Thus it is that the water supply of this high land, while in general larger than that of the arid region, is not available for the needs of agriculture in the regions below.

From Evanston northward the river passes through a valley which narrows in places and finally turns abruptly to the west. Near this locality is a site suitable for a reservoir; also at the junction with Salt Creek is another small reservoir site, having an average width of a quarter of a mile and a length of nearly 1 mile. From the mouth of Salt Creek the river runs almost due west for 7 miles, the first 2 miles being through a narrow canyon, which opens into a valley three-quarters of a mile in width. Here the river crosses the line from Wyoming into Utah. The valley continues open to and below the town of Woodruff, at which point the open land is about a mile and a half in width. The river then turns almost due north, continuing for about 25 miles in the Territory of Utah.

This valley, from Woodruff northward, continues to widen, until at Randolph it is nearly 3 miles from side to side. At the mouth of Saleratus Creek, which enters above Woodruff, is a wide valley, varying in width from 1½ to 3 miles, and upon which water is now taken to a small extent from the Bear River, the headworks of this canal being in Wyoming. Near the mouth of Saleratus Creek the Randolph Canal, reported to be 16 feet in bottom width, is diverted, and follows along the west side of the valley. Below Randolph the river flows slightly to the east again. The valley continues nearly 3 miles in width, with wide meadow lands, then narrows to a width of about a mile and a half. Continuing northwardly and crossing into Wyoming, it widens out to from 3½ to 4 miles. At this point are great ranches, some of the finest grazing lands of the State of Wyoming being at this locality, one ranch in particular extending about 8 miles along the river.

This portion of the river in Wyoming flows in a valley from 1 to 3 miles wide, with the same rich bottoms along its course. At intervals ditches divert water to cover the lower bench-lands on which hay

DRAINAGE BASIN OF THE BEAR RIVER

and other forage plants are raised. Near the mouth of Smith Fork the valley narrows on the west, and the bench lands almost if not quite disappear. A gauging of Bear River was made above the mouth of Smith Fork by Henry Gannett on August 24, 1877, and the stream was found to carry but 112 second-feet. The preceding season had been unusually dry and the discharge was probably less than the average for that season.[1] On Smith Fork, which has a drainage area of 314 miles, are several favorable reservoir sites, covering from 100 to 250 acres, and located 25 miles or more above the mouth, but there is little agricultural land along this stream and few ranches. The discharge of this fork in the fall of 1889 was estimated to be about 200 second-feet.

At the head of Smith Fork is a natural reservoir, known on the maps as Lake Alice, formed by a mass of loose material which has slid from the mountain into a narrow gorge, blocking the outlet of a long, narrow valley. This natural dam has made a lake nearly 2 miles in length by a quarter of a mile in width at the widest point, the water slowly escaping by percolation through the mass of loose material.

Below Smith Fork the first important tributary of the Bear is Thomas Fork, which flows southward along the line between Wyoming and Idaho, the mouth of this fork being in the latter State. The valley of Thomas Fork is but about 2 miles wide, and contains a large area of fine agricultural land, with but little water, the conditions here being the reverse of those prevailing on Smith Fork. Along the latter is little agricultural land, but an abundance of water, while along the Thomas Fork there is an abundance of land and a scarcity of water. It has been proposed to take water from Smith Fork and carry it around the point of the mountain into Thomas Fork Valley. A canal of a bottom width of 12 feet has already been begun.

From the mouth of Thomas Fork Bear River runs southwesterly and then northwesterly, passing through the range of low hills which bound Bear Lake on the east. In this portion of the river are many small areas of meadow land from a quarter to a half mile in width. A ditch is taken out, covering a wide strip of meadow on which hay is raised, and several others are projected to take water from the river upon land above the town of Montpelier.

BEAR LAKE.

The Bear River, emerging from the boundary hills between Wyoming and Idaho, enters the Bear Lake Valley at an elevation of about 5,800 feet. In the northern end is Bear Lake, a beautiful sheet of water 20 miles in length by 7 in width, surrounded on all sides except the north

[1] See Report of Henry Gannett, topographer, p. 697, in the Eleventh Annual Report of the U. S. Geological and Geographical Survey of the Territories, embracing Idaho and Wyoming, being a report of progress of the exploration for the year 1877. F. V. Hayden, Washington, 1879, 720 pp.

by ranges of steep hills. On the north end of this lake is the great marsh or slough which is indicated on the Land Office maps as the Upper Lake. In the fall of 1889, when visited, there had been a succession of dry seasons and the marsh had almost entirely disappeared, only a small area of open water at the south end, adjoining the lake, being left. In other portions of the marsh the ground was perfectly hard; roads crossed it in various directions; the greater portion of the area was covered with hay ranches, and dotted here and there by houses and hay stacks. Although the inhabitants of the valley can not enter and patent this land because of the fact of the official designation as a lake, yet they have made entries on the county records which are considered among themselves as binding. North of the marsh the valley continues nearly level for some miles, then the rolling hills on either side gradually close in and the river again enters narrow defiles.

Bear River does not flow directly into Bear Lake, but in times of high water floods the marsh, and from thence the water backs into the lake. In time of drought the water in turn flows from the lake into the marsh, and in many tortuous channels finally enters the lower portion of the river at the north end of the valley. There is no well defined passage through the marsh, the river where it enters dividing into channels and, spreading through this low land, finally converges upon its lower reaches. The lake and marsh thus have a modifying effect upon the régime of the river, cutting it into two portions, the Upper Bear River, above Bear Lake Valley, and the Lower Bear, below that point, the action of the upper river being felt only indirectly in the lower.

Bear Lake lies across the boundary between Utah and Idaho, the most southerly portion of the lake being in Utah, the northern in Idaho. On the south and east of the lake are strips of fertile land already populated by a community of farmers and fishermen. To the north in the broad valleys are many towns, some of which are of considerable size, depending for their prosperity upon the agricultural resources of that region. The elevation is too great for many of the crops that are grown in the valley of Salt Lake, frosts occurring in August and even in the latter part of July. The lands both along the lake and north of it are irrigated by canals taken from the streams which flow into Bear Lake Valley, principally from the mountains on the west. All of the ordinary flow of these streams is utilized, and the seepage water alone, excepting in times of flood, escapes into the lake and marsh at the north. Very little water is taken from Bear River itself. There are, however, a few canals taken from the upper river above the point at which it enters the valley and carried out upon the bench lands upon the eastern side of the valley south of the town of Montpelier.

The lake is separated from the marsh to the north by a long, low ridge of sand, thrown up by the waves to a height of from 2 to 5 feet above the ordinary water level. This sand ridge is about 5 miles in

BEAR RIVER CANYON, UTAH.

length and from 100 to 300 feet in width. It is pierced in two places by narrow passages, through which the water flows from the lake into the marsh, or from the marsh to the lake, depending upon the relative elevation of each.

In the fall of 1889 the Bear Lake and River Canal Company was by means of plow and scraper raising this natural embankment by scraping up the sand from the shore of the lake and dumping it on top, the object being, it was asserted, to increase the storage capacity of the lake by blocking the natural outlet. It was obvious, however, that such construction could be of little if any use toward this end, but was undertaken as a preliminary step toward the attempt to acquire some right or title to the use of this lake as a storage reservoir.

LOWER BEAR RIVER.

North of Bear Lake Marsh the river flows northwesterly and then westerly to Soda Springs through very narrow valleys with occasional strips of meadow land. The bounding hills are of irregular rounding outlines and are suitable only for grazing. Around Soda Springs are large areas of level land, wild and uncultivated, the town itself depending for support upon the springs, which attract to it a number of summer tourists. Beyond Soda Springs to the north and west stretch broad lava fields, extending to and beyond the Snake River. The Bear River on entering this lava flow is deflected toward the south, and for a time flowing upon it, finally cuts a deep channel and continues in a gorge.

From Soda Springs down to the north end of Gentile Valley the valley proper is underlaid by lava, but in places contains some irrigable land. On the east side the mountains come down to the river; on the west side is the lava plain. As gauged August 17, 1877, by Henry Gannett at Soda Springs, Bear River was found to carry 1,000 second-feet.[1]

In the northern part of Gentile Valley a company or association of irrigators has begun work toward constructing a ditch on each side of Bear River to irrigate a broad lava plain or bench. In some places, however, the soil of this is so thin that the lava is exposed to view, and in others the surface is so broken as to be unfit for irrigation. Thus it appears to be an unpromising locality for advantageous employment of water.

Gentile Valley is a prosperous agricultural region. Unlike Cache Valley and most of the valleys of Utah, each person lives on his own farm and not in a village. The houses are usually well kept and have been constructed with care, several of them being of brick. Nearly all the water for this valley is taken directly from lateral creeks which flow from the mountains on each side, there being but one completed ditch taking water from Bear River. In the valley the river has a very slight

[1] Eleventh Annual Report of the Hayden Survey, p. 698.

fall, this being the chief obstacle to the diversion of canals. A large portion of the valley, especially the lowlands along the river, is devoted to meadows. The rolling lands away from the river are planted in wheat, as are also a few of the foothills, on which are grass and alfalfa. Warm Creek and Bridge Creek, both rising in springs, empty into the river from the east, the first about 2 miles above the lower canyon, the other 4 miles above. The spring at the head of Warm Creek flows about 50 second-feet and supplies four ditches.

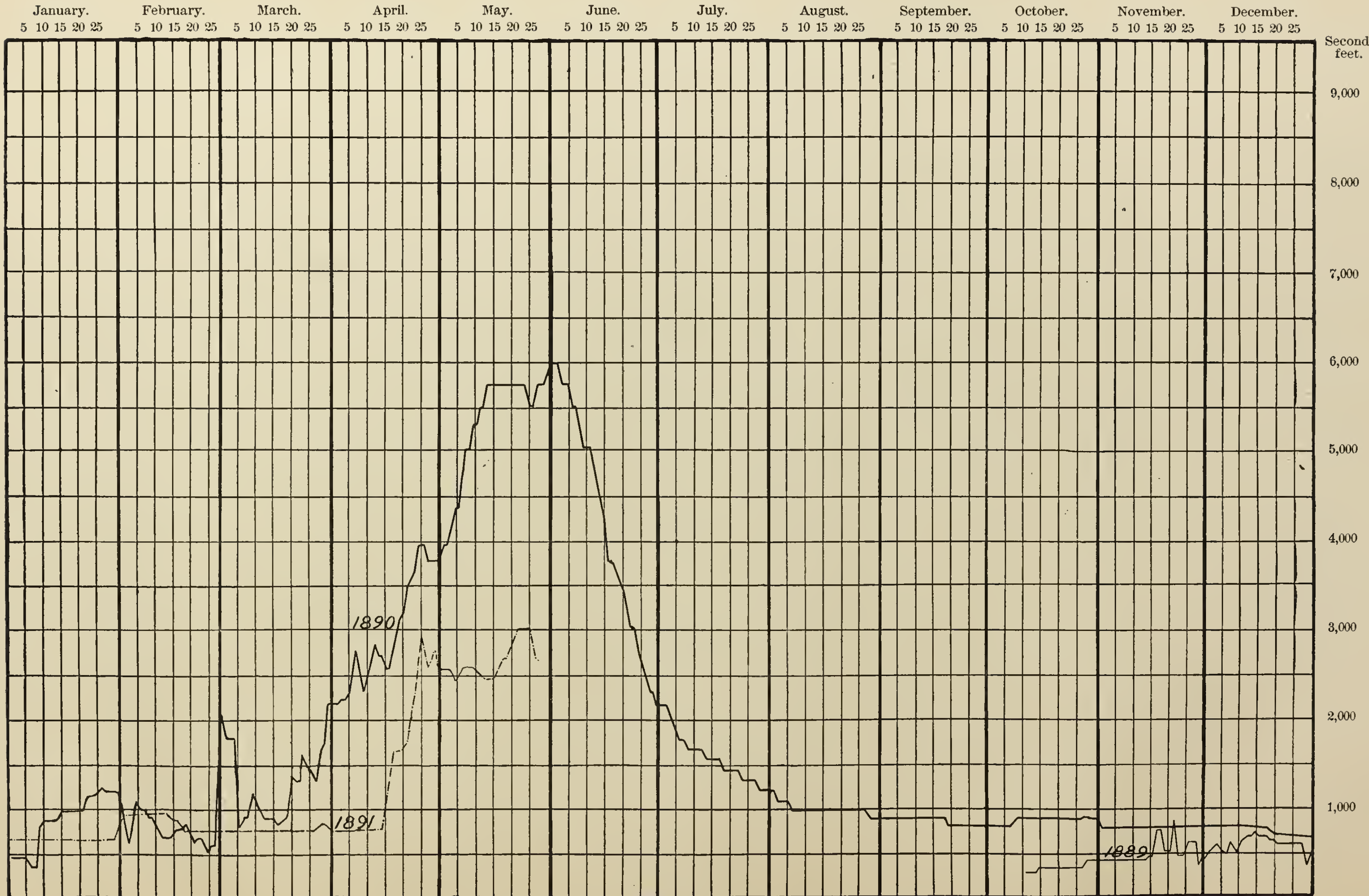
In the lower end of Gentile Valley Cottonwood Creek enters upon the west. The land along it is for the most part rough and nonirrigable. This creek is unlike the creeks emptying into Bear River in Gentile Valley on the east side. The volume varies greatly in the spring and summer and in dry or wet seasons, since it does not head in large springs, but depends upon the water from mountain slopes far to the west. In the summer of 1889 it was very low, and even the few ranches depending upon it suffered for water. The scarcity of that year was ascribed in part to the growing use of water on small hay ranches high up on the stream. It is doubtful if reservoirs can be constructed on account of the gravelly, open character of the soil and rocks.

Below Cottonwood Creek, on the east side, is Mink Creek, supplied by three large springs about 6 miles from Mink Creek Settlement, and discharging about 75 second-feet, this quantity of water being in excess of the needs of the tilled lands. The waters are clear and cold and therefore are not as desirable for irrigation as those of Bear River would be. The cultivated areas are on the hillsides, as there is very little level land.

CACHE VALLEY.

Cache Valley has been termed the "granary of Utah." It is one of finest of the large valleys of that Territory and contains many towns and villages dependent upon agriculture for support. The northern end of this valley lies in Idaho, the line between Utah and Idaho crossing the valley from east to west. At the north the land is high, sloping in a series of terraces toward the south. On this high ground several ditches have already been dug, winding about among the hills and deriving their water from the creeks entering the valley from the northeast. The Bear River is relatively at too low an elevation to cover the highest of this ground.

In the gorge north of the Cache Valley, about 3¼ miles from its mouth, there is an excellent site for a reservoir, a 30-foot dam making a pond 1·7 miles long, the first mile being on an average of 1,500 feet wide and the upper portion 800 feet wide. The elevation of the river at this proposed dam site, referred to the datum of the Utah and Northern Railroad, is 4,687 feet. Above this point the bottom land rises for 2 miles at the rate of 18 feet per mile, and then for a half mile at the



DAILY DISCHARGE OF THE BEAR RIVER AT BATTLE CREEK, IDAHO.

rate of 30 feet per mile. From the proposed dam down-stream is a rapid fall for 3¼ miles to the mouth of the canyon, where the elevation, referred to the same datum, is 4,620, the first mile falling at the rate of 25 feet, and then at about 18 feet per mile. From the mouth of the canyon southerly down river the fall is 19 feet per mile to Riverdale settlement, 2¼ miles below. From there down the fall varies from 24 feet to 6 feet per mile to Battle Creek railroad bridge and gauging station, which is 8½ miles below the canyons, the elevation of the water there being 4,477 feet. The diagram of discharge at this point is shown on Pl. XCIV, and the monthly means are given in the tables appended.

From the railroad bridge the fall varies from 3·8 feet to 6·8 feet per mile, for about 5 miles, to an elevation of 4,450. At about this place the rapids disappear and the fall becomes more gentle, being from 1·0 to 2·5 feet per mile as far down as Franklin and Benson road bridge, nearly 10 miles below Battle Creek bridge, at which point the elevation is 4,436. For 3 miles below this bridge the fall continues at 2·5 feet per mile, then decreases to 0·5 per mile, varying from this to 1·5 through the rest of the Cache Valley, excepting at two or three places where small riffles occur, the fall there increasing to the rate of 5 feet per mile. From the Franklin-Benson bridge for 35 miles down, following the river, the fall averages 1·11 feet per mile, the elevation being at that lowest point 4,397 feet.

This shows that the river falls sufficiently to enable a canal taken out at the reservoir site before noted to cover a large part, if not all, of the high-lying bench lands on the west side of the valley, lands of wonderful fertility, but which are now useless for the lack of water, and also that sufficient elevation can be obtained in the gorge of Bear River to enable a canal to be taken out to cover the bench land in the vicinity of Preston. A large portion of these flats, however, is now irrigated by a ditch from Cub Creek, and another canal is being constructed to take water from Mink Creek.

Cache Valley, with the exception of a part of the west side, is perhaps the best watered of any valley of the Territory. Besides the Bear River, which flows through it from north to south, but from which very little water is used, there are a number of large tributaries rising in the high mountains to the west of Bear Lake. The principal of these are Cub Creek, Logan River, Blacksmith Fork, and Box Elder Creek. On the west side are also one or two streams, but these, though supplying a considerable area, are of less importance, and a large area is left unwatered. On the headwaters of the Logan River and Blacksmith Fork are a number of localities at which storage reservoirs could be built, but these are of a small area and only of local importance. The results of measurements made of the discharge of Logan River have been given in the previous annual report.

The necessities of many of the inhabitants of the west side of Cache

Valley have forced them to attempt water storage, and it is instructive to note the progress in this direction. A brief description of the reservoir built by the residents of the town of Newton may be instructive, not that there is anything remarkable about this, but because it is in many ways typical of a number of small reservoirs in various parts the arid region.

Newton Reservoir is situated in the southwestern part of Cache Valley, about 3 miles north of the village of Newton, from which it derives its name, and upon the lands adjoining which the waters are used. The reservoir is on a somewhat rolling and broken plain, into which Clarkston Creek has cut, forming this basin. When full the water surface is 2 miles long, has an average width of about 250 feet and an area of 147 acres, with an average depth of water of about 6 feet, the capacity of the reservoir being thus from 800 to 900 acre-feet.

The waters are confined by two dams, one on each side of a hill at the north end of the reservoir, the smaller of these dams being used as a waste weir. The main dam is about 500 feet long and 30 feet high at the highest point. It is constructed of earth, the outside slope being about 4 to 1 and the inside one being 3 to 1. The steeper inside slope is formed of a series of steps, these steps or terraces being held up by sheet piling of 3-inch plank. The dams could be raised 10 or 15 feet at a moderate cost and the capacity of the reservoir thus largely increased. The drainage area of Clarkston Creek is 40 square miles, more than half of which is mountainous.

The first dam was built by the people of Newton eighteen years ago, and has continued to be owned solely by the landowners and water-users of that village. All of their cultivated lands, to the extent of 1,000 acres, are irrigated solely from this reservoir, and without it the village would be deserted and the lands return to their original desert condition, as the water of Clarkston Creek is entirely consumed by the farmers of Clarkston during the irrigation season. With the present capacity of the reservoir no more than 1,000 acres can be cultivated. Practically the whole of this acreage is in wheat. An "irrigating head," that is, the quantity that an irrigator can readily distribute on his land, or a stream of 3 to 6 second-feet, is allowed to run for two hours for each acre for the first watering, and for the second an "irrigating head" for one and a half hours per acre, two waterings being usually sufficient for a crop of wheat.

To construct the reservoir $7,000 was originally contributed in cash, labor, or in material, and there have been subsequent assessments to an unknown amount, three dams being carried away in succession and rebuilt. For Clarkston Creek to fill the reservoir usually requires from two to three weeks, but in 1889, an exceptionally dry year, with light snowfall, the gates were shut the 1st of March and the reservoir was barely filled before irrigation began.

The second irrigation is usually finished about July 1, and the reser-

DAILY DISCHARGE OF THE BEAR RIVER AT COLLINSTON, UTAH.

voir is then entirely drained. It has happened that the reservoir has been refilled during the summer by storm waters, but this is very exceptional and is not to be depended upon. In September, 1889, at the time the reservoir was empty, the creek, then at a minimum, was discharging about 5 second-feet through the site.

In the lower part of Cache Valley Bear River turns rapidly to the west and passes out through a deep, narrow canyon, known as "the Gates," entering the Salt Lake Valley. In this canyon (see Pl. XCIII), in the fall of 1889, one of the largest canals of the West was begun, it being designed to carry 2,000 second-feet. The head works are placed in the upper end of the canyon, where a low dam raises the water into the canals, these latter being built along the side of the canyon partially in open cut and partially in tunnel. One branch runs almost directly west across the Malade River and covers the large plain north of Corinne, and the other branch is intended to continue down on the east side of the valley through the various towns and farms along the foothills, finally ending in the city of Ogden.

At the time at which the work upon this canal was begun there was, owing to the exceptionally dry season, considerably less than 1,000 second-feet in the river. This fact was well known, and uneasiness was felt by the older appropriators of water all along the river as to the probable action of the company building these canals, and their feelings were voiced in a protest made at the Idaho State convention and in appeals to the Federal authorities.

It is obvious from a broad, comprehensive knowledge of this river system, from a consideration of the climate of its upper courses and the wasteful utilization of the water for hay meadows in high altitudes, that the effort should be made, if the water is to be used to the best advantage, to discourage larger occupation of the lands at the headwaters. There should also be an attempt made to prevent the imposing upon these lands of inefficient, imperfect, or defective systems of water utilization and of canal or reservoir construction. The water supply of the whole region being limited, the high-lying areas should not be developed to the injury of better lands or of older water rights.

The settlers, however, are pushing up into these high altitudes, where no crops except hay can be raised, and there they are using enormous quantities of water in a wasteful manner, turning it out without system or economy upon tracts of grazing land, converting these into meadows where only the coarser grasses can grow. This water, which in former times following the course of the river came into the lower altitudes, was used by the older settlers upon crops of far greater value.

There are two gauging stations on this river, one at Battle Creek, Idaho, below the railroad bridge formerly used by the Utah and Northern Railroad, the other at Collinston, Utah, in the lower end of the canyon below Cache Valley, being thus below the head works of the new canal just mentioned. The daily discharges at these localities are shown on Pls. XCIV and XCV respectively.

These diagrams are very similar in general appearance, that for the lower station showing the increase in water received from the many tributaries entering the Bear in Cache Valley. The most notable feature in both cases is the smaller discharge for the year 1891. Comparing these with the diagrams of discharge of rivers in California and Nevada, a striking feature is the comparative steadiness of the flood discharge in May and June, the river gradually reaching a maximum, remaining at or near this point for days or weeks, and then declining slowly and steadily, and without those great fluctuations so characteristic of the streams before mentioned. Much of this regularity of flow is due doubtless to the fact that a large part of the flood comes from a great distance and from many tributaries, the irregularities of any one being to a certain extent neutralized by those of others, and also to the influence of Bear Lake midway in the course of the river.

THE OGDEN AND WEBER RIVERS.

These rivers rise in the Wasatch Mountains southwest of the Bear drainage, and flowing in a general westerly direction enter the Salt Lake Valley a short distance below the point where the Bear flows into Salt Lake. Their catchment areas are thus in many ways similar in topography and climate to those of the more southern tributaries of the Bear, and the fluctuations of their waters present many points of similarity. The gauging stations of these rivers are in the canyons above the heads of irrigating ditches, thus obtaining the full discharge of each stream.

On Pls. XCVI and XCVII the discharges of these streams are given, that of the Weber being continued till June, 1891. It is noticeable in this case, as in that of Bear River, that the discharge for 1891 is smaller to a marked degree than that of 1890. The steadiness of the spring flood is also remarkable, being similar to that of the Bear, though less regular. These rivers have, however, no large lakes to act as equalizers of the discharge, the water coming directly from the snows on the lofty mountains.

UTAH LAKE DRAINAGE.

Utah Lake is a body of fresh water, very shallow, with an extreme length of 22 miles and greatest width of 7 miles, the water supply coming almost entirely from the Wasatch Mountains, with very little from the low-lying foothills on the north and south, or from the Lake Mountains on the west. The principal river flowing into the lake is the Provo, which enters on the east side near the city of the same name. North of this is the American Fork River, and south of it the Spanish Fork, also Hobble Creek, Payson Creek, and Salt Creek, which comes from the valley to the south. In the summer and fall these streams are very small, in some cases their beds are almost dry, but in spring they are rivers of considerable size, and occasionally take the

character of mountain torrents, bringing an enormous quantity of water to the lake. Along the shores of the lake, especially on the west side, are many springs, some hot or warm, but the amount of water which these underground sources contribute is small in comparison with that which flows on the surface.

The daily discharges of the American Fork and Spanish Fork rivers during the low water of 1889 and flood of 1890 are shown on Pl. XCVIII, the American Fork occupying the upper part of the diagram, and the Spanish Fork the lower. In the case of the former stream the gauging station was destroyed by a flood due to the bursting of a dam, but the probable discharge, obtained from considerations of other data, is shown by the dotted line, making a complete year. The American Fork drains an area of about 66 square miles, while the Spanish Fork receives water from an area of 670 square miles or over ten times as much. The diagram shows, however, that the discharges are nearly equal, that of the American Fork being somewhat smaller. An exact comparison of the relative run-off of these two streams can be seen by referring to the table on page 104 of the preceding annual report.

The discharge of the Provo River is given on Pl. XCIX for the low water of 1889 and through 1890 up to June, 1891. The smaller discharge of this latter year is noticeable, showing that the decrease of run-off characterized a large part of the country.

The water of these and other tributaries after entering Utah Lake if not evaporated is discharged toward the north by the Jordan River. This, when the water was at a much higher level, cut a deep notch in the edge of the basin through which it flows into Salt Lake Valley, this deep cut being located at what is now known as the "Point of the Mountain." The level of the water of the lake varies from month to month, rising in the spring, usually reaching its highest in May or June, and then falling steadily until the beginning of winter. Besides this fluctuation by seasons there is is a wide annual range, the average level for the year rising or falling through a series of years, the extreme range of water level since the settlement of the country being about 12 feet.

No systematic record of the discharge of Utah Lake through Jordan River has been kept, although the water in seasons of scarcity is apportioned to the various canals. The matter is of such fundamental importance to the county and city of Salt Lake, as well as to various canal companies, that it seems strange that no record has been made of the amount taken by the various canals or flowing to waste. On May 21, 1889, Mr. J. Fewson Smith ascertained by weir measurement that the discharge was 218 second-feet. In the latter part of June the discharge began to diminish, and by September the flow had declined to 48 second-feet. During the succeeding winter there was a heavy snowfall in the mountains, and in the summer following the supply in the lake and river was ample for ordinary needs, so that measurements were not made.

The fluctuations in the surface of this lake from month to month are shown in Fig. 229, beginning in 1883. This year was marked by the greatest rise as yet recorded, the unusual snowfall of the previous winter being rapidly melted by the warm rains of spring and bringing a great quantity of water to the lake, submerging the shores and causing large loss to the people of Utah County occupying the low lands. The top of the flood line for each successive year, to and including 1889, is seen to be less and less, the lake in no succeeding year reaching at its maximum a height equal to that of the preceding year.

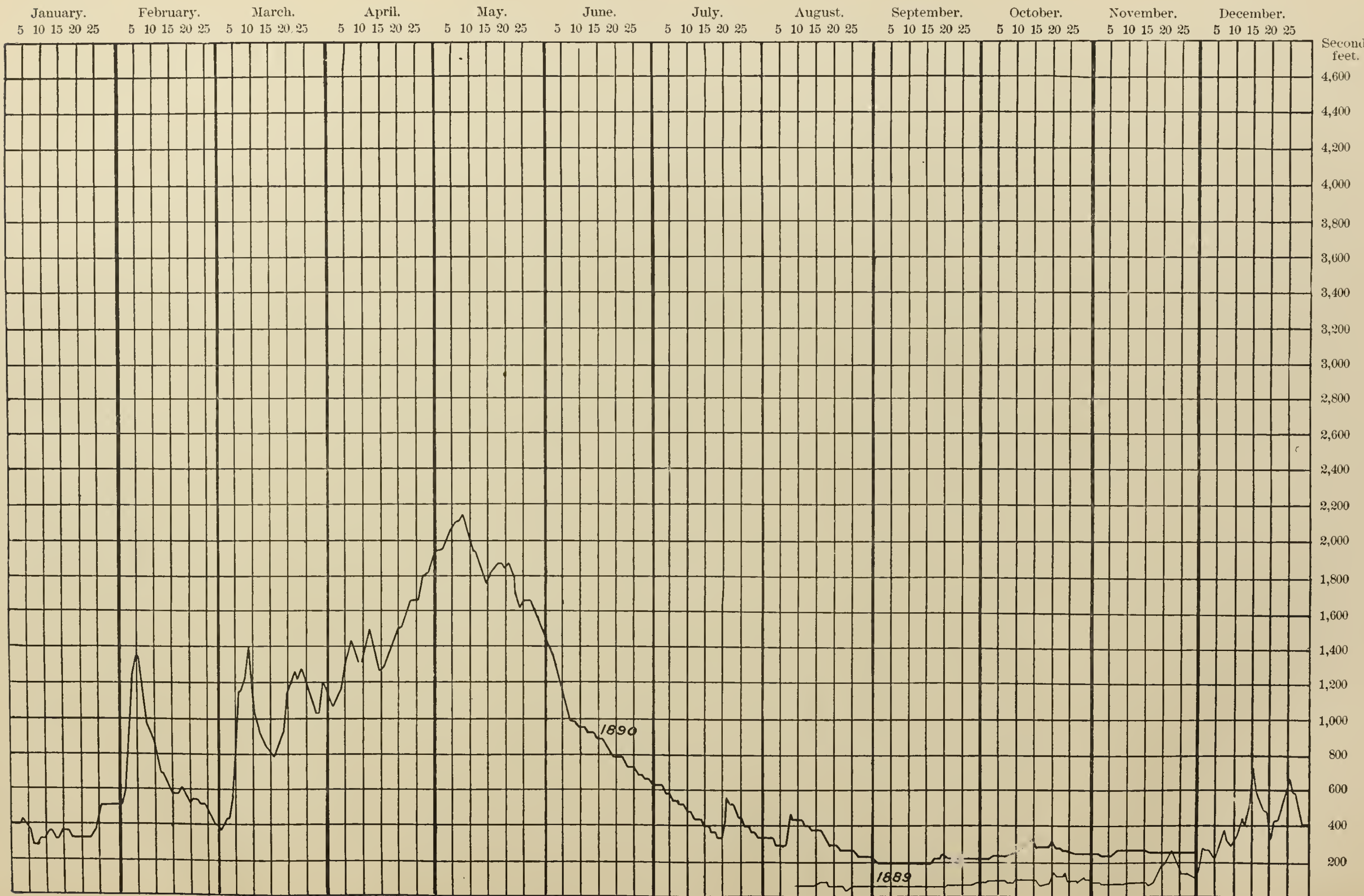
As the shores, excepting on the west side, are very low and with gentle slope toward the lake, the inclination in places being less than 4 feet to the mile, this variation of surface increases and diminishes the water area greatly, the shore advancing or retreating over a strip of land from 1 to 2 miles or even more in width. It may be said that for every foot

FIG. 229.—Diagram of fluctuations of Utah Lake.

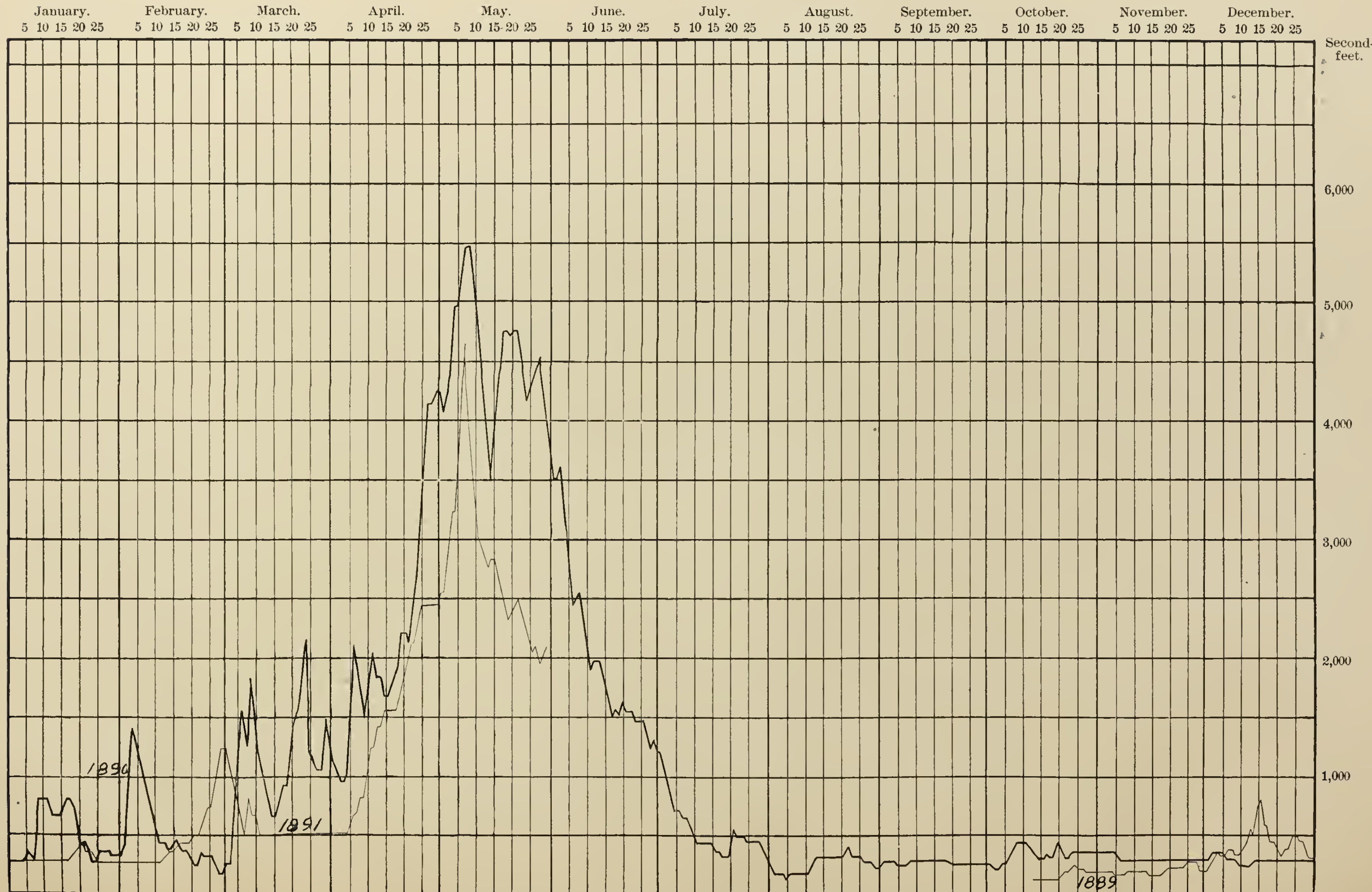
rise about 1,000 acres of pasture lands are submerged, and on the contrary, for every foot fall this amount of land is restored to use. These bordering lands are of great value to the people dwelling around the shores of the lake, for the arable and pasture lands of Utah County, being at the best somewhat restricted, are all utilized.

On the other hand, the waters of the lake discharged through the Jordan River are of prime importance to the inhabitants of Salt Lake County, for upon this water depends the larger portion of the cultivation of that broad and fertile plain. In 1874 a dam was built in the Jordan at the "Point of the Mountain," where the first decided fall or riffles of the water occur, its purpose being to raise the water to the height of the two highest canals. On the one side, in Salt Lake County, there is more land to be irrigated than water to cover it, and, on the other side, around Utah Lake, are enormous tracts of land whose value depends upon keeping the level of the lake to the minimum.

A survey of the lake was made in 1889 at a time when, owing to unusual droughts, the water was lower than it had been for nearly ten



DAILY DISCHARGE OF THE OGDEN RIVER ABOVE OGDEN, UTAH.



DAILY DISCHARGE OF THE WEBER RIVER ABOVE UINTA, UTAH.

years, and large bodies of land previously inaccessible from the soft and treacherous character of the surfaces could be traversed with ease. The map showing the result of this survey is on Pl. XCV of the preceding annual report of this Survey.

On the north and east the profile of the land bordering the lake showed a decided storm beach or ridge of sand from 2 to 5 feet above the average level of the water at that time, and from 100 to 200 feet in width. Behind this were marshes intersected by strips of open water from 1 to 5 feet deep, and filled with a luxuriant growth of tall weeds and bushes. This ridge holds back the seepage water which comes from the farms above, and retains the water in the marsh in places from 1 to 2 feet higher than that in the lake, but during the late spring and summer this usually either escapes to the lake or dries up.

In general the lake acts as an equalizer or safety valve for the great floods which come from the high, steep slopes of the Wasatch Mountains. In its natural condition it discharges freely during the summer and fall through the Jordan River, the velocity and discharge of that stream depending upon the height of the water in the lake. It is evident from the floods that have occurred in times past that the Jordan in its natural condition could not deliver during the autumn and winter all of the water which came in during one or two months of flood in the spring. From this it resulted that before the dam was built the lake has had a decided range from year to year.

As to the precise influence of the dam in the Jordan, observations are not as yet of a sufficiently detailed character to reveal this clearly. It is obvious, however, that while the dam influences to a certain degree the height of the water in the lake, and holds back during the summer a considerable amount of water, it can not in the long run obliterate or greatly modify the variation from year to year. Its influence will be in the direction of making the floods higher, but its removal would in nowise obviate the danger or probability of their occurrence.

The area of the lake at low water is approximately 80,000 acres, and the evaporation from the surface, the lake being shallow and exposed to the winds, is enormous in comparison to the amount discharged through the Jordan. In order to estimate the quantity of water thus passing into the air, it will be necessary to make some assumptions, from the fact that direct measurements of evaporation from this lake are very difficult. The amount of evaporation from pans 3 feet square has been obtained at certain places, as described in the preceding annual report of this Survey,[1] and estimates of the relative evaporation at Salt Lake City have been carried on by the Signal Service, U. S. Army.

The evaporation investigations of this latter organization were carried on in a uniform manner in various parts of the United States by means of a small instrument called the Piche evaporometer, described in the Monthly Weather Review for September, 1888.

[1] Eleventh Annual Report, U. S. Geological Survey, Part II, pp. 30-34.

The possible evaporation at Salt Lake City, as obtained by computations based upon the use of this instrument, is given in the table below, in connection with the results of measurement of evaporation from a pan in the reservoir at Fort Douglas, the military post outside the city. From a consideration of these figures and other data, a depth of evaporation, given in the sixth column, has been assumed for Utah Lake.

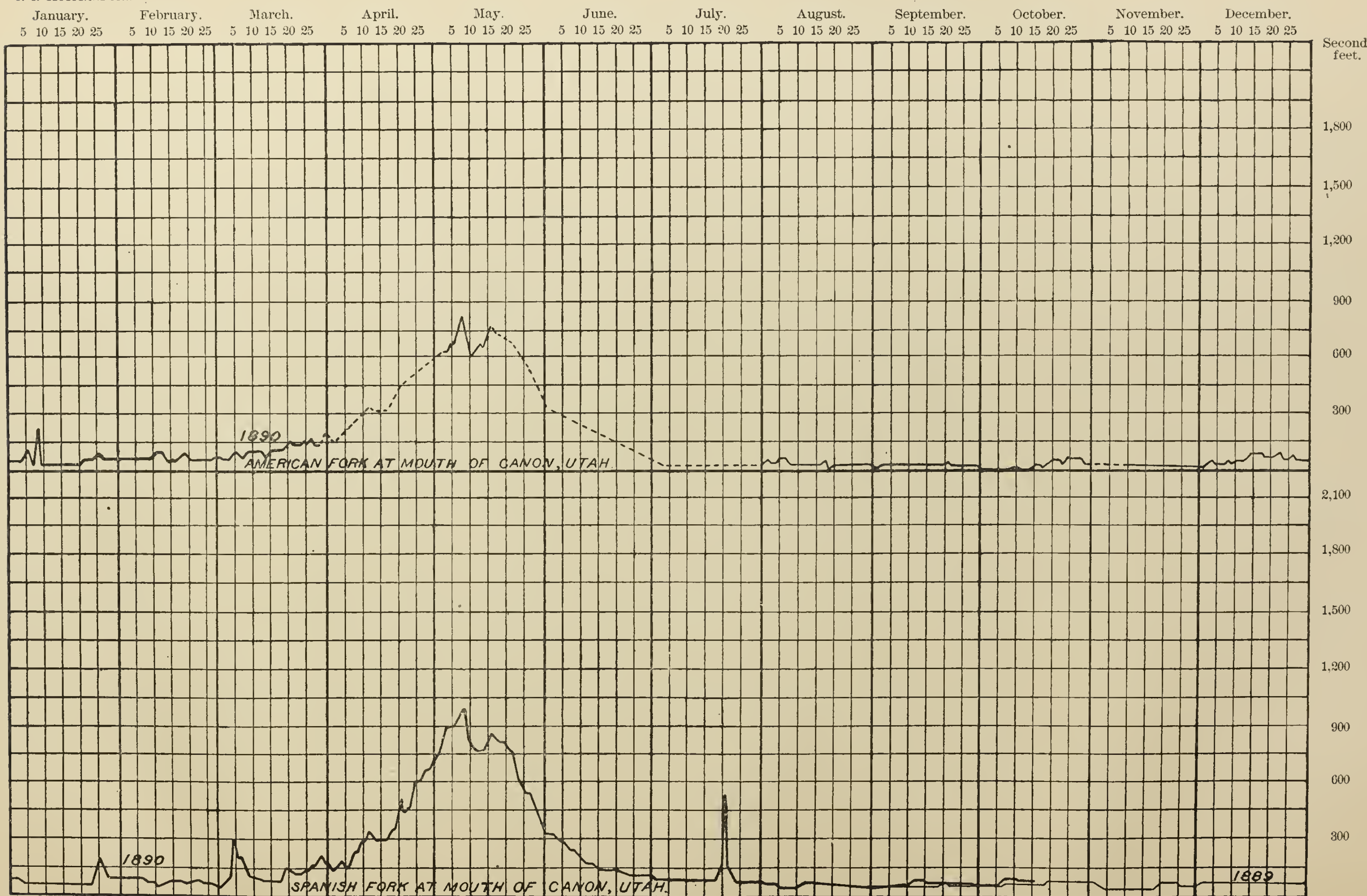
Monthly evaporation.

Months.	Salt Lake City. Piche.	Fort Douglas evaporating pan.			Utah Lake, assumed evaporation.		
		1889.	1890.	1891.	Inches.	Acre-feet.	Second-feet.
	Inches.	*Inches.*	*Inches.*	*Inches.*			
January	1·8	....	*1·0	....	1·0	6,666	108
February	2·7	....	*1·5	....	2·0	13,333	240
March	3·6	....	*2·5	....	3·5	23,333	380
April	7·2	....	3·7	3·2	5·0	33,333	559
May	6·9	....	4·1	4·8	5·0	33,333	542
June	8·9	....	5·1	5·2	7·0	46,666	783
July	9·2	....	7·6	7·6	8·0	53,333	866
August	10·7	10.5	6·5	6·5	8·4	56,000	911
September	9·6	5·7	4·6	5·2	7·0	46,666	783
October	6·5	4·9	2·1	2·5	5·4	36,000	586
November	5·0	1·0	1·2	1·4	2·0	13,333	224
December	2·3	....	*1·1	....	1·7	11,333	184
Total	74·4	....	41·0	....	56·0	435,429	†514

* Assumed. † Mean.

If, for example, during January the lake has a surface area of 80,000 acres and loses only 1 inch in depth, the total loss for the month would be 6,666 acre-feet, an amount sufficient to supply a stream flowing at the rate of 108 second-feet. In February, the area remaining constant, but the evaporation increasing to 2 inches, the loss would be 13,333 acre-feet, or 240 cubic feet per second. These quantities are given in the seventh and eighth columns, being computed on the basis of a loss in depth per month, as given in the sixth column, from a constant area of 80,000 acres. The mean loss by evaporation throughout the year, according to this conservative estimate, is 514 second-feet.

The mean discharge of the Provo, the principal feeder of the lake, for the year from July 1, 1889, to June 30, 1890, was 532 second-feet, and for the year from July, 1890, to June, 1891, was 472 second-feet. For the American Fork, from August 1, 1889, to July 31, 1890, the mean discharge was approximately 149 second-feet, and for the Spanish Fork, from September 1, 1889, to August 31, 1890, was 172 second-feet. These are results obtained by measurements in the canyons above the agricultural land of Utah County. Not all or even perhaps half of this water reaches the lake, as the greater part is diverted to the fields and there evaporated. Comparing, however, the total flow of the Provo with this computed evaporation, it is apparent that the whole discharge of this stream, including the floods, is necessary in order to counterbalance the loss by evaporation, and also that the united discharge of the Amercan Fork and Spanish Fork is only about 60 per cent of this loss.



DAILY DISCHARGE OF THE AMERICAN FORK AND SPANISH FORK AT MOUTH OF CANYONS, UTAH.

A comparison of these and other facts shows that the lake is in effect too large to be most effective as a storage reservoir. In other words, the efficiency of the lake as a reservoir would be greatly increased if its area could be reduced even to less that half of its present extent; for by so doing in years of scarcity, as those of 1888 and 1889, a large proportion of the water which reaches the lake, instead of being lost by evaporation, would be retained and held for use in canals which cover the land of Salt Lake County. On the other hand, considering this question from a theoretical standpoint, if the lake were only one-half its present area, the floods which come in years of exceptional precipitation would cause a far greater proportional increase of water surface than now takes place, for this water, being thrown into a smaller lake and being able to escape but slowly through the Jordan River, would of necessity encroach upon a far greater proportion of the surrounding lands.

Thus, while to obtain the maximum amount of water in years of scarcity it would be better if the lake were small, yet to take care of the floods, which will happen at intervals of from five to ten years, it is necessary that the lake have a flood area as large as it now has, or even what it would have at the highest water. From consideration of these points the segregation of the land around and under the lake was made to a contour line which should be 5 feet above the low-water mark of 1879.[1]

SEVIER RIVER.

The Sevier rises in the high plateaus of southern Utah, flows northerly about 300 miles, then turns abruptly to the west and southwest, finally losing its waters in Sevier Lake, an alkaline sink. All along its course the water is diverted for purposes of irrigation, the development of agriculture by this means being so great that during the summer the entire flow is utilized. On the head waters of this river are many reservoir sites, probably the largest and most valuable of any in the Territory. The river with gentle current winds through broad valleys, then plunges through deep, narrow canyons, alternately assuming the character of a tortuous, sluggish river and a mountain torrent. At the lower end of these open valleys the descent of the river is so small that there are frequently large marshes, and at the lower edge of the marsh the advantages for building a dam and holding back the surplus water in the river are unsurpassed.

A storage reservoir can be built at the lower end of one valley, and the water being discharged through the canyon can be taken out in the canals already built upon the lands of the valley next below. At the bottom of this valley another reservoir can be constructed, from which in turn the water discharging through the narrow gorge can be again taken into canals and utilized in turn upon the valley next succeeding. Thus a system might be provided which, if properly utilized, would en-

[1] Eleventh Annual Report U. S. Geological Survey, Part II, p. 183.

able a large proportion of the water to be used over and over again in the course of this river system.

The highest and most southern of these reservoirs is that situated at the middle of Plateau Valley, or, as it is sometimes called, Panguitch Hayfield, on the east fork of the Sevier near its headwaters. Here, at an elevation of about 7,200 feet, is a small lake and marsh. The altitude is too great for crops to mature, but in this hayfield a number of ranches have been fenced where forage is raised as winter feed for the herds which in summer range through the valley and over the adjoining summits. The disadvantage of reservoirs at this place is the comparatively small drainage areas above them and their distance from the tilled lands.

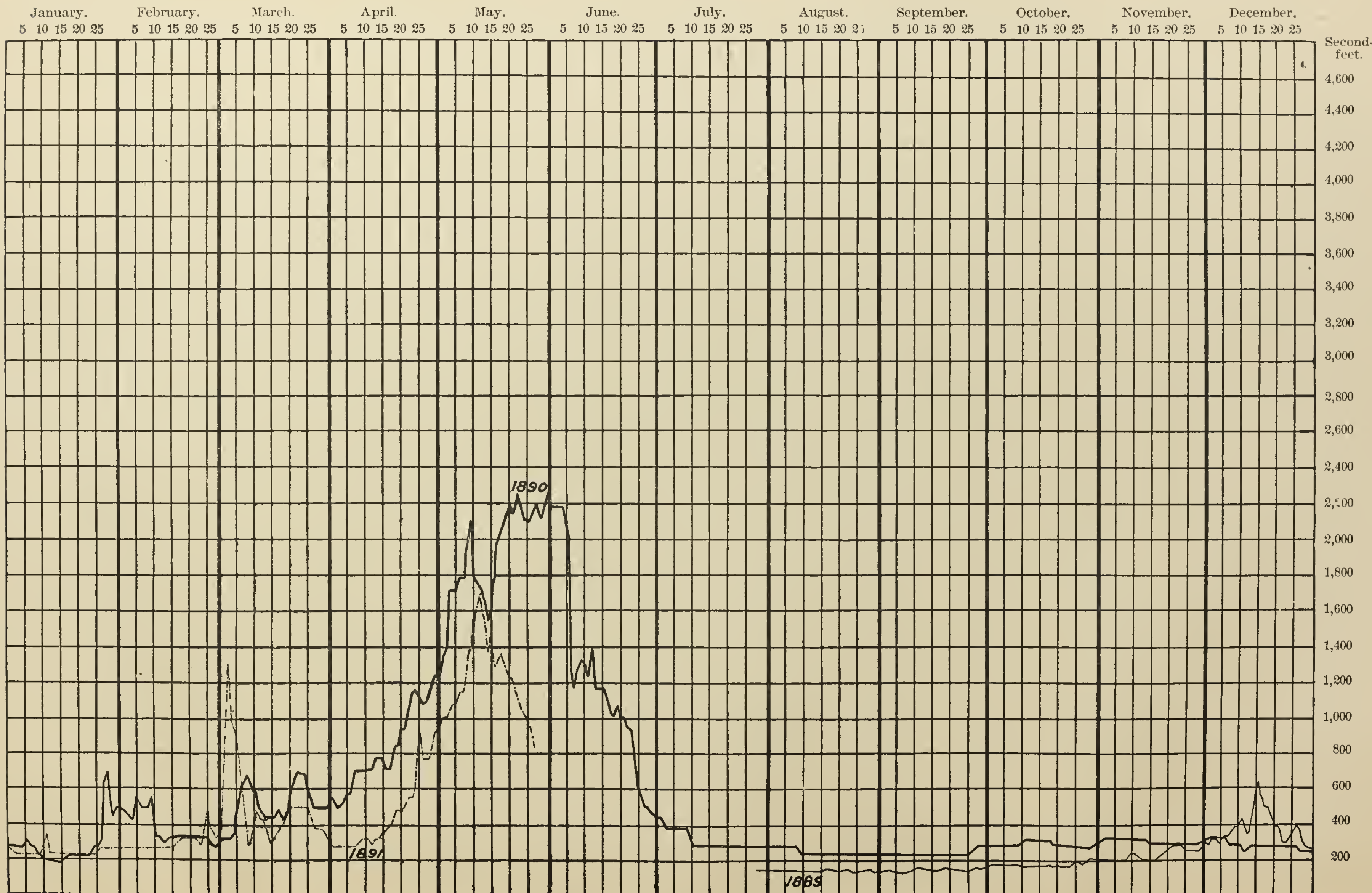
The next location in order is about 15 miles northeasterly from that above mentioned at the lower end of the Plateau Valley, and at a point where the East Fork of the Sevier enters its first canyon. The elevation is 7,000 feet, and the area drained into this proposed reservoir is larger, including that noted above. The situation is far more favorable, as the dam can be much shorter, and there is in the vicinity an abundance of material, both rock and earth, for constructing a dam.

If a company succeeds in building a reservoir at one of these places, an important question will arise, namely, as to how it will be possible to distinguish the water which is thus acquired by storage from that which would naturally flow in the river. In other words, what steps can be taken to prevent others from receiving the benefit of this stored water; as, of necessity it must be turned back into the river channel, which it will follow for 50 miles or more.

Bordering this upper Plateau Valley on the east side in the summits are also a number of small lakes admirably adapted for storage on a small scale, but which it seems unnecessary to describe, as their aggregate capacity is less than any one of the reservoir sites on the main stream.

The best place for water storage on the whole river is probably that on Otter Creek at its junction with the East Fork. Here is a marsh at the lower end of Grass Valley, at an elevation of 6,500 feet, about one-half mile in width, extending up the valley for a mile or more. The average fall of the water surface here is from 6 to 9 inches to the mile. Otter Creek discharges through a narrow notch about 180 feet wide, where a dam can be built at very small expense. The drainage area above this point is large; but should it prove insufficient to fill a reservoir basin of the capacity proposed it is possible at small expense, by building a canal from the east fork of the Sevier, to carry the entire flood waters of this stream with its enormous drainage area into this reservoir. There is already a small ditch on the site of such a canal, so that it is evident to the casual observer that here exist all the advantages for storage on a large scale.

The facilities at this point are well known and have frequently been



DAILY DISCHARGE OF THE PROVO RIVER AT PROVO, UTAH.

examined and discussed, and unfortunately, perhaps, for the canal owners below, they are fully appreciated by the persons who claim to own the greater portion of the land in the proposed site. The elevation in this basin is too great for most crops, but large quantities of hay are raised and the marsh affords excellent pasturage for cattle.

Below this marsh, on the East Fork, where it enters the canyon, are several other excellent opportunities for building a dam at the lower end of stretches of level land on which water can be impounded. There is a choice of sites here, and careful surveys and soundings for bed rock will be necessary before a final decision can be made.

All the localities mentioned above are on the East Fork of the Sevier. The West Fork drainage also includes a large number of excellent localities, among which is Panguitch Lake, well known as a locality where by the expenditure of a comparatively small amount a dam can be built, increasing the contents of the lake and holding a large amount of flood waters. From 2 to 3 miles above and southwest of the lake are other points at which storage works could be constructed, the most notable being at or near the wonderful Blue Spring, which adds a large volume to Panguitch Creek.

The situation on the Sevier is typical of that which prevails in other sections of the country. The older settlers came at first into the lower valleys and took out small ditches upon the lands most favorably located, though these were not always of the best quality. As these irrigators acquired property and other inhabitants flocked in, the ditches were enlarged and new ones, taking water at points a little higher in the river, were built, the process being continued until all of the available water at that place was taken out. In the meantime other settlements higher on the river were being made, and these in turn built larger and better ditches. The younger men and newcomers, not finding sufficient land and water in the older communities, continued to go higher and higher on the river, taking out new canals, which in turn diminished the water supply of the river below. Now the very headwaters of the river are reached, and settlers are coming to altitudes too great for the raising of most crops, but where wood and water are abundant. There they turn out upon the high pasture lands the water of the springs and smaller tributaries, wastefully using large quantities in this manner and diminishing the flow of the river itself. Without some regulation the matter must adjust itself finally by the limiting or even decrease of agriculture in the lower and more fertile valleys.

The Sevier, after passing through the canyon below Marysvale, enters upon the main Sevier valley, near the head of which is the town of Joseph. Above Joseph a stream known as Clear Creek enters from the left or west side, which, even in the dry season of 1888 and 1889, discharged a considerable volume of water. In the latter part of July it amounted to about 25 second-feet. On the headwaters of this creek are numerous localities suitable for small storage reservoirs, but the drain-

age area is too small for the establishment of any comprehensive system which will be of widespread benefit to the valleys below. The locality is, however, favorable for small projects which can be executed by one or more canal companies.

At and below Joseph City the main canals supplying the Sevier Valley are taken out from the river, covering a large amount of fertile land. The elevation of this valley is approximately 5,000 feet, and the climate is such that all the grains and fruits of the temperate zone mature to perfection. Besides the water of the main river all of the smaller tributaries entering both from the east and from the west are utilized to their full extent, mainly by individual farmers or by neighborhood associations. At Richfield, the principal town of the valley, is a large spring, which contributes greatly to the prosperity of the place.

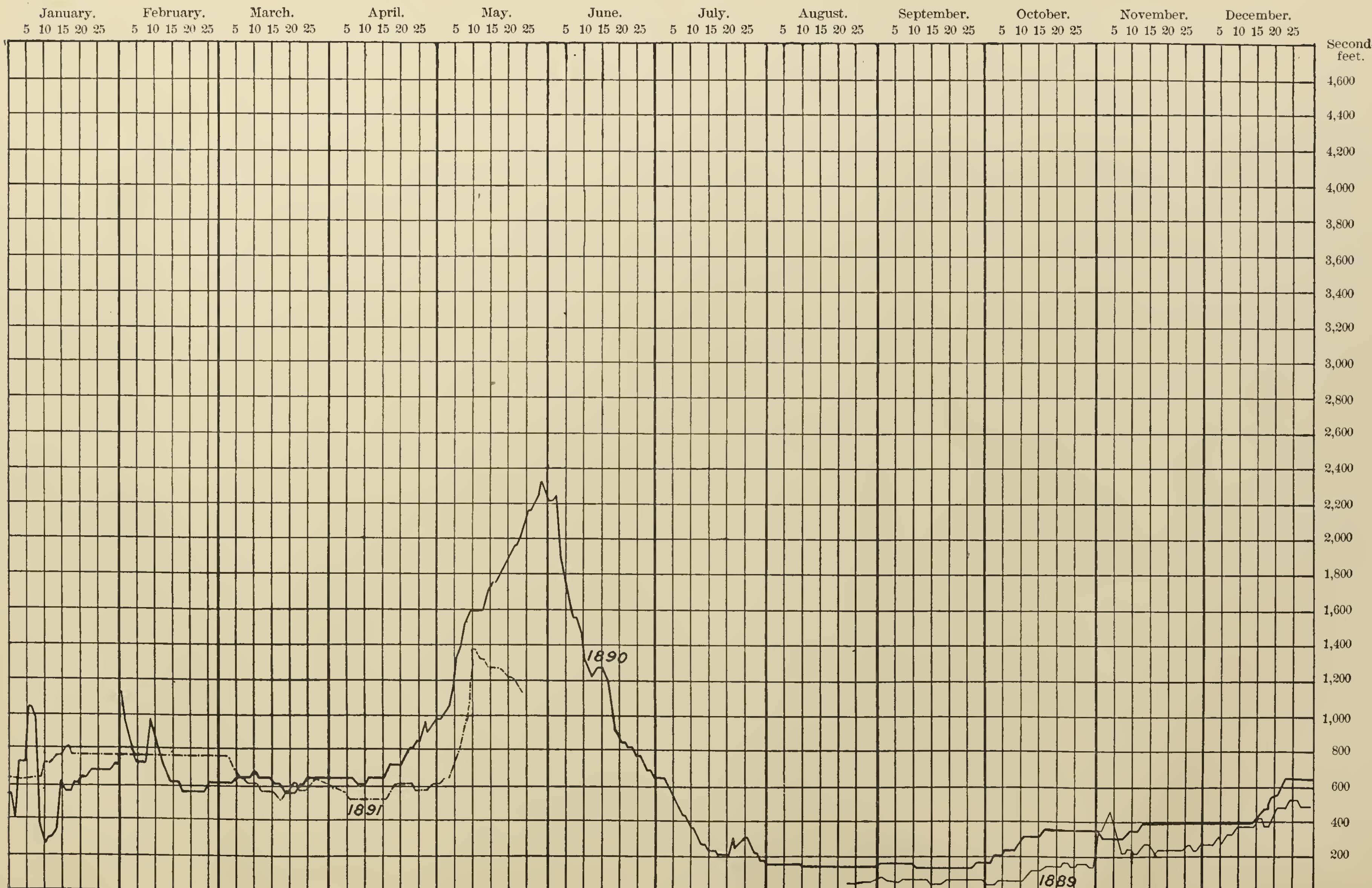
In flowing through the valley from Joseph northward to Gunnison all of the water is taken out of the river, and in 1889 there were three separate places along its course where the bed was dry. Below each of these places a certain amount of water returned to the river, to be caught in succession by tight dams built across the bed of the stream. In times of flood these dams are almost, if not entirely, swept away, but are replaced at the beginning of the dry season and made tight as the water diminishes in volume. Below Gunnison the Sanpitch River enters the Sevier, carrying, however, in the latter part of the crop season, a very small amount of water, if any.

There are in addition several very favorable localities for water storage on the Sanpitch and its tributaries, notably on Nine Mile and Twelve Mile creeks, most of which are, however, in use as ranches or hay meadows.

Below the junction of the Sanpitch with the Sevier the valley is still wide and contains large bodies of fertile lands, to which, however, little if any water can ever be taken. Below the settlement of Fayette the bounding hills approach each other, and finally the river enters a deep canyon, above the mouth of which is a favorable location for holding water. After passing through the canyon below Fayette there are intervals of comparatively open country and small flats of a few acres scattered along the river.

Near Juab, a station on the Utah Central Railroad, are several strips of marsh and pasturage which drain through Chicken Creek into the river. On this creek have already been constructed one or two small artificial ponds, where the water, which rises principally in springs, is collected and allowed to flow down as needed upon the small pieces of agricultural lands below. Again, along the river below Chicken Creek, are a number of localities where water might be held, notably at the railroad station called Wellington, also at Mills Station and at Church House.

At the town of Leamington the river finally leaves the broken, hilly country and begins to traverse the great plain of the Sevier Desert,



DAILY DISCHARGE OF THE SEVIER RIVER AT LEAMINGTON, UTAH.

cutting its way first through a great accumulation of gravels, the delta of the ancient river. At this point two canals have been taken out to supply the town of Leamington and the agricultural district below. About 40 miles farther down is the Deseret Reservoir. At this point the inhabitants of the towns of Deseret and Oasis have cut a channel for the river 460 feet long, shortening the course about a mile, so that the river, instead of pursuing a tortuous channel around a large loop, now pours through this cut-off across what was previously a narrow neck of land. The loop thus abandoned has been blocked up at both ends by earth dams and is now used as a reservoir, receiving its water by a long canal which runs up the river until it reaches a point sufficiently low for the water to be diverted into it.

There is at present constructed, running from this reservoir, a canal which passes out through a cut 22 feet deep and 24 feet wide on the bottom, which leads to the town of Deseret. A new canal is projected to take water from the middle of the old reservoir and irrigate other lands for the purpose of starting a new colony. The local engineers have estimated that, by raising the earth dams and building better regulating gates, sufficient water can be held in times of floods to supply the needs of this new community.

This reservoir will be an example of storage at low elevations near the land to be irrigated. The situation is such that it is almost impossible to provide a better system for these towns. The Sevier winds through so many long, fertile valleys in its course, the water being taken out by innumerable canals, that it is impossible for the irrigators living out on the desert to provide storage for themselves in the high mountains, for the question of the distribution of water which has flowed through five or six counties would involve interminable conflicts. Their only resource, therefore, is to attempt to hold some of the flood and seepage water which has come from the irrigated lands a hundred miles or more above.

From the above description of the river and the towns and communities depending on its waters for sustenance it will be seen that the most careful study must be made of all the conditions before a general system of storage can be inaugurated which will be beneficial to all. There is no doubt that reservoirs in the mountains at the headwaters will be of great value and advantage even to the people who live down in the Sevier desert, as by their presence in the mountains the summer flow of ground water must be increased. On the other hand, to directly benefit the lower towns it will be necessary to construct at points in the lower end of several of the populated valleys reservoirs which will hold at these points the local flood waters, and deliver them to the agricultural lands in the next valley below.

But before any such system of storage can be successfully carried into effect a general understanding will be necessary among the towns and counties interested, by which the whole body of irrigators shall

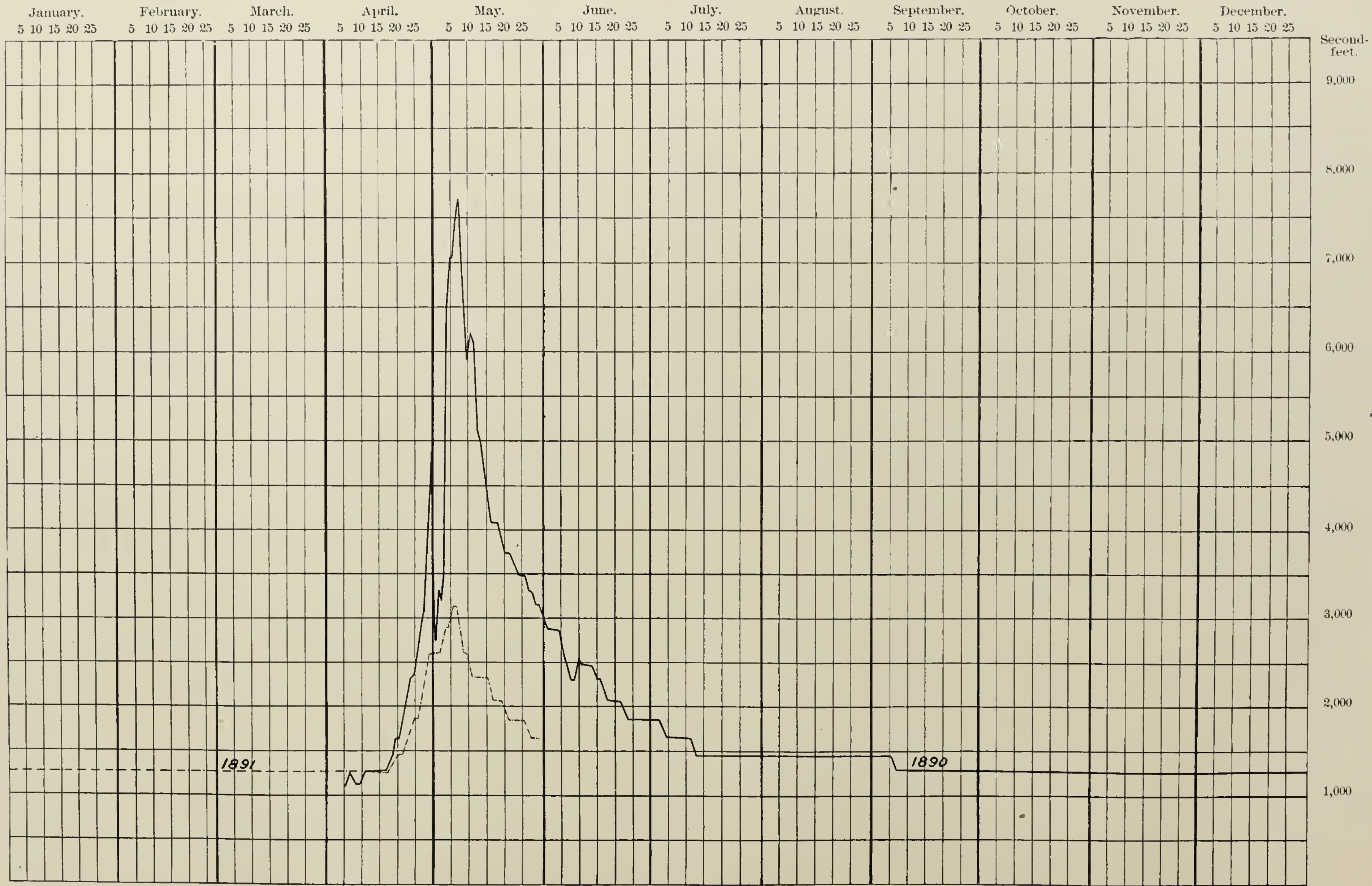
join in the system of water storage and then distribute the waters thus saved according to the judgment of all interested.

The discharge of this river at the Leamington gauging station from August, 1889, to June, 1891, is shown on Pl. C., the less discharge of this latter period being very noticeable. The amount of water passing this station is of course greatly affected by the large diversions of water all along the river, and in years of scarcity, as in 1891, the flood discharge must come mainly from the lower tributaries, that from the higher forks of the stream being used in the many large canals.

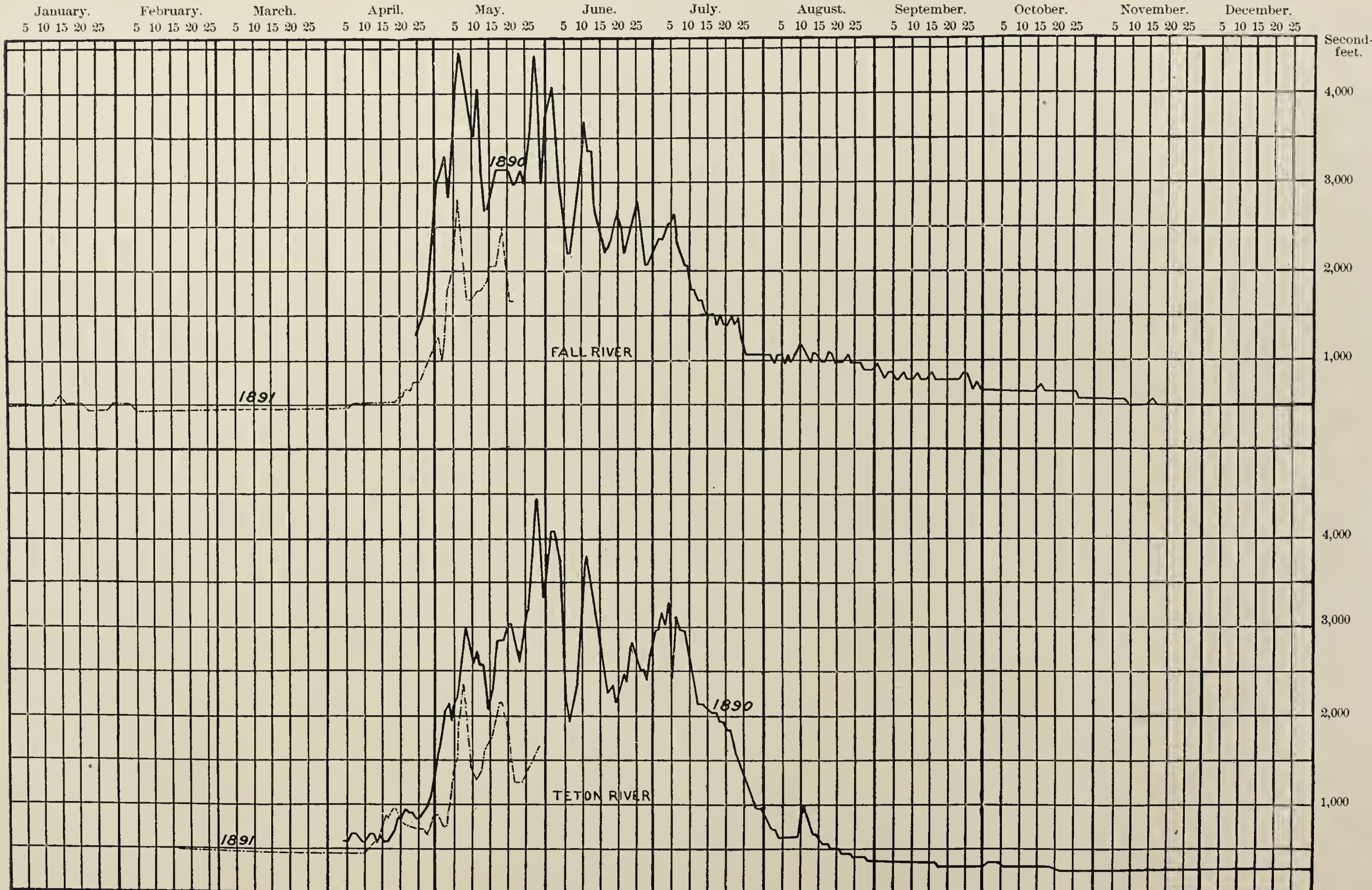
SNAKE RIVER DRAINAGE.

Stream measurements have been made of the principal tributaries of the Snake River in eastern Idaho, and also of lower tributaries in western Idaho and Oregon. A brief description of the topography of the country and of the gauging stations was given in the preceding annual report. The discharges at these stations are shown on Pls. CI to CVI. The discharges for Henry Fork, Falls River, and Teton, as well as for the Snake at Eagle Rock or Idaho Falls, are similar in general character, differing mainly in the quantity of water represented, but the diagrams for the Owyhee, Malheur, and Weiser exhibit distinctive characteristics, only to be explained by a careful study of the topography of the region.

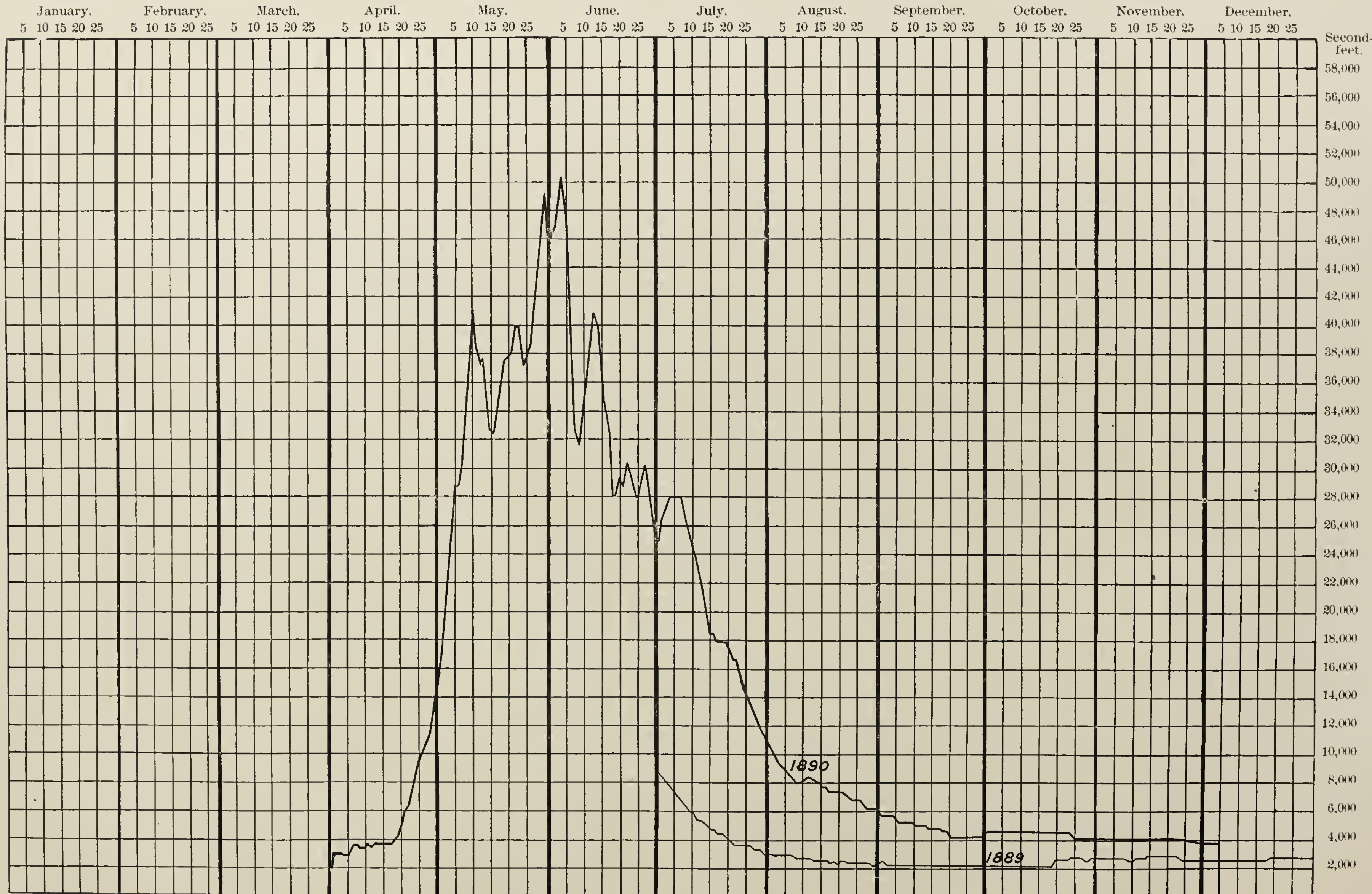
The diminished floods of 1891 are very noticeable, and these are not only less in quantity, but culminate at an earlier date. The diagram for the Weiser is peculiar for the number and extent of the fluctuations of high and low water and the irregularity of the time at which these occur.



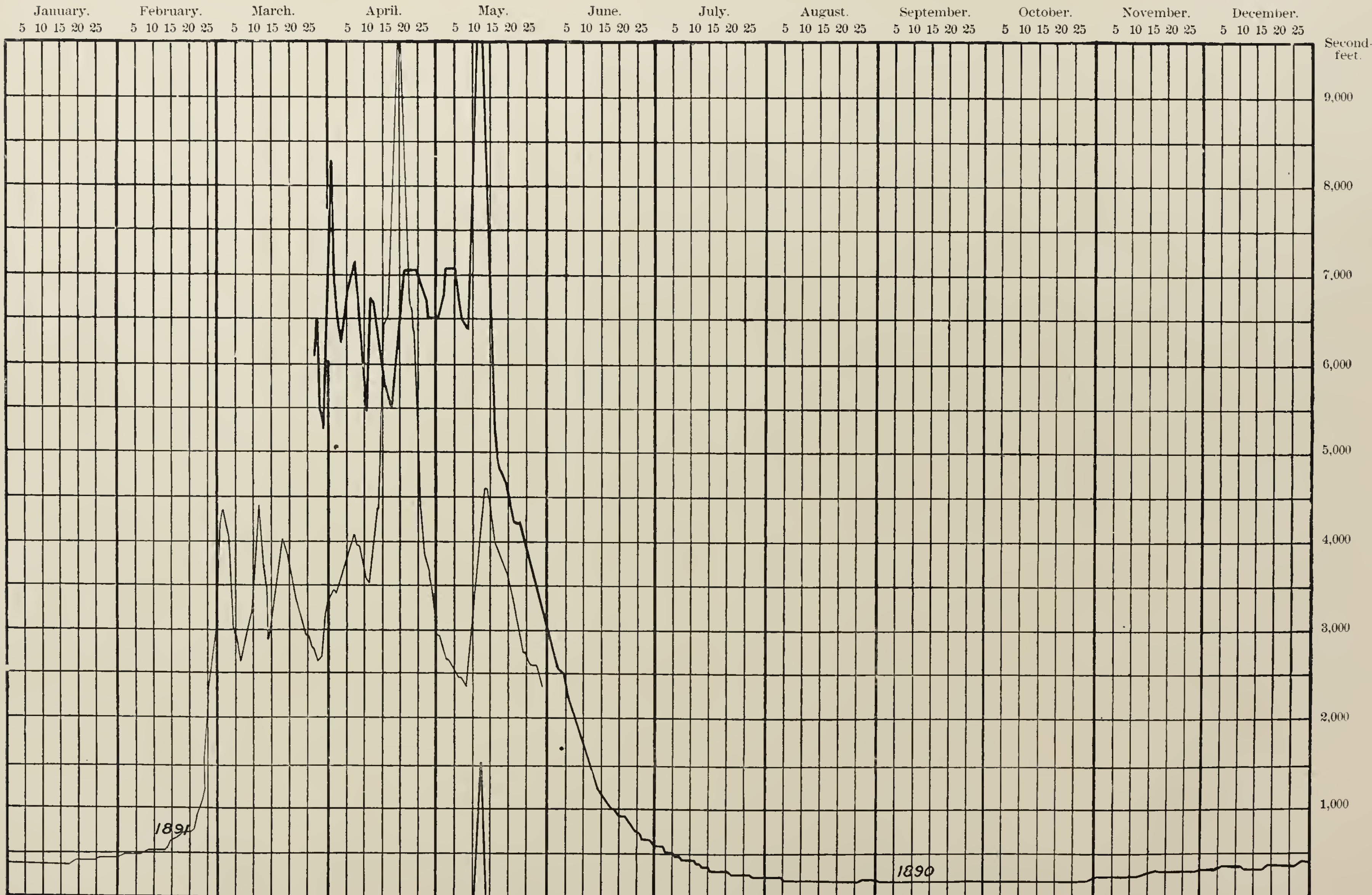
DAILY DISCHARGE OF THE HENRY FORK ABOVE FALLS RIVER, IDAHO.



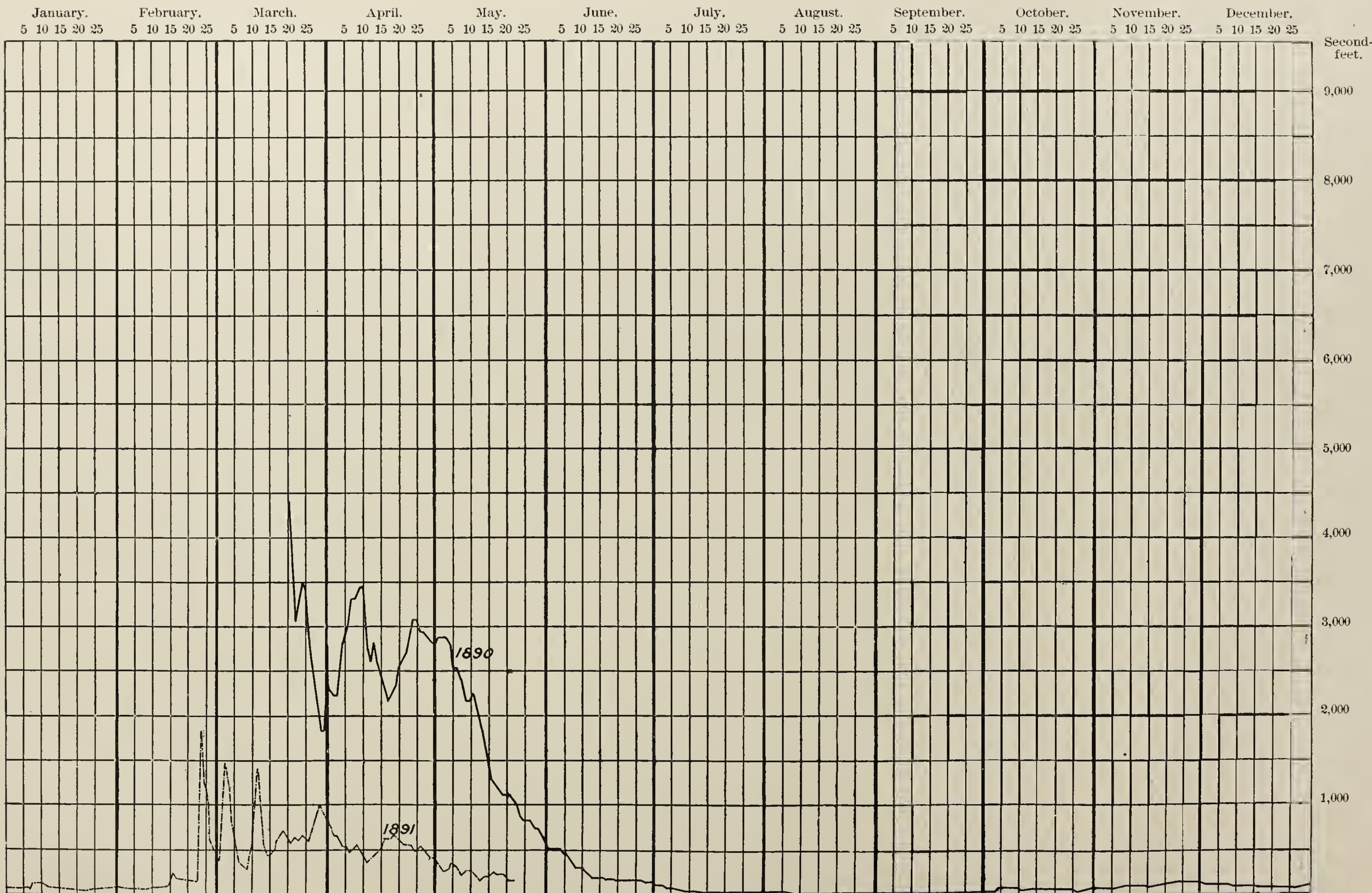
DAILY DISCHARGE OF FALLS AND TETON RIVERS ABOVE CANALS, IDAHO.



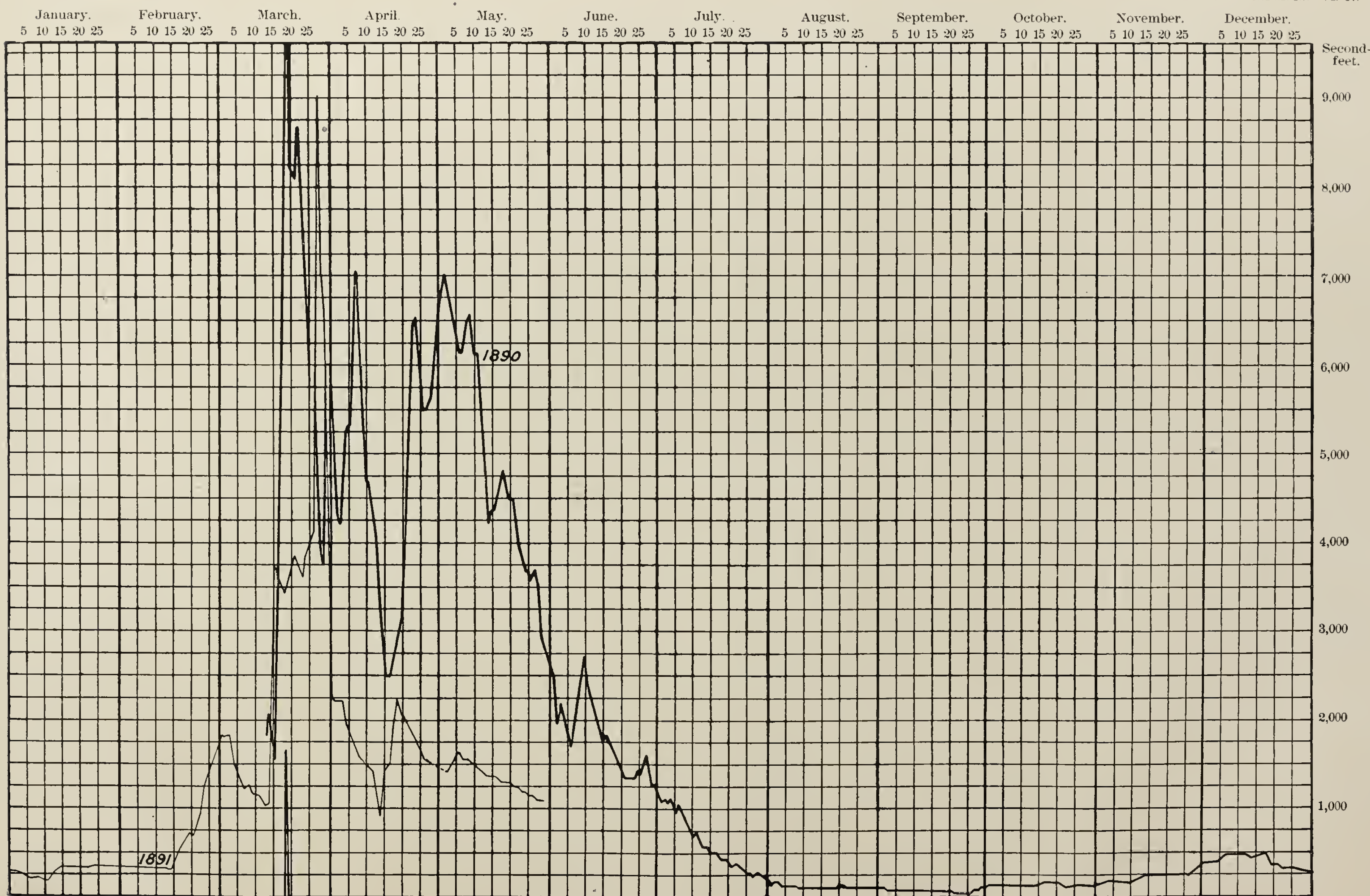
DAILY DISCHARGE OF THE SNAKE RIVER AT IDAHO FALLS, IDAHO.



DAILY DISCHARGE OF THE OWYHEE RIVER AT RIGSBY, OREGON.



DAILY DISCHARGE OF THE MALHEUR RIVER AT VALE, OREGON.



DAILY DISCHARGE OF THE WEISER RIVER ABOVE WEISER, IDAHO.

DISCHARGE TABLES.

The following tables give the monthly discharges for the rivers upon which observations of height have been made during the year ending June 30, 1891. These tables are similar in form to those published in the preceding annual report of this Survey,[1] being in fact continuations of many of them. At the head of each table is the name of the river and also the locality at which the measurements were made, together with the total drainage area in square miles above this point.

The first column gives the month, and in cases where observations were made during a portion of the month, the dates during which these were continued are shown immediately after the name of the month. In such cases the mean discharge is not that of the whole month, but of this fraction only. Under the head of "discharge" are given the maximum, minimum, and mean discharges for each month or portion of month in cubic feet per second. In several instances to complete a year estimates have been made of the mean discharge, these estimates being marked by an asterisk.

At the right of the mean discharge in second-feet are the total discharges for the entire month in acre-feet; that is, the number of acres that would be covered to a depth of 1 foot by a stream of this given size flowing continuously through the month, none of the water being lost. The last two columns on the page show the relation existing between this quantity of water and the area from which it may be supposed to have come. For purposes of comparison it is assumed that this water came in equal quantities from each square mile or acre of the drainage basin, although as a matter of fact this is recognized as impossible, since in nearly all cases the water running off a large drainage basin comes from comparatively restricted localities.

The first of these two columns gives the depth of run-off for each month in inches; that is to say, this quantity of water would, if put upon a plain of equal area, cover it to the depth given. The last column gives the run-off in second-feet for each square mile of the basin; or, in other words, each square mile, taking the average for the entire area drained, contributed a constant supply of the given number of second-feet.

[1] Eleventh Annual Report of the U. S. Geological Survey, Part II, Irrigation, pp. 93–106.

West Gallatin River, near Bozeman, Montana.

[Drainage area, 850 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
August 16 to 31	437	402	426	26,200	0·58	0·50
September	640	402	450	24,550	·54	·53
October	437	367	402	24,700	·54	·47
November	....	....	*400	23,800	·52	·47
December	....	....	*400	24,600	·54	·47
1890.						
January	....	....	*320	19,680	·43	·38
February	....	....	*320	17,760	·39	·38
March 23 to 31	320	320	320	19,680	·43	·38
April	1,255	280	460	27,400	·60	·54
May	3,195	1,300	2,092	128,600	2·84	2·46
June	3,800	2,060	2,641	157,300	3·47	3·11
July	2,165	890	1,388	85,362	1·88	1·63
August	890	570	761	46,800	1·03	·89
September	690	570	607	36,100	·80	·72
October	650	570	591	36,400	·80	·70
November	570	430	506	30,100	·66	·60
December	....	....	*450	27,650	·61	·54
1891.						
January	....	....	400	24,600	·54	·47
February	....	....	400	22,200	·47	·47
March	....	....	450	27,675	·61	·53
April	....	....	500	29,750	·65	·59
May	2,535	1,390	1,897	116,665	2·57	2·23
June	2,975	1,615	2,516	149,702	3·30	2·95

* Estimate.

Madison River at Red Bluff, Montana.

[Drainage area, 2,085 square miles.]

1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	....	....	*1,200	73,800	0·66	0·58
February	....	....	*1,200	66,600	·60	·58
March	....	....	*1,200	73,800	·66	·58
April 4 to 30	2,580	1,370	1,620	96,390	·87	·78
May	6,420	3,060	4,823	296,600	2·67	2·32
June	6,360	3,780	4,977	296,131	2·66	2·38
July	3,660	1,715	2,518	154,800	1·39	1·21
August	1,640	1,375	1,535	94,400	·85	·74
September	1,580	1,420	1,466	86,300	·78	·70
October	1,520	1,420	1,498	92,300	·83	·72
November	1,470	1,285	1,380	82,150	·74	·66
December	1,520	1,285	1,400	86,150	·77	·67
1891.						
January	1,580	1,240	1,406	86,469	·78	·67
February	1,580	1,265	1,436	79,698	·72	·69
March	1,790	1,470	1,631	100,306	·90	·78
April	1,960	1,640	1,774	105,530	·95	·85
May	4,260	1,790	3,389	208,423	1·88	1·62
June	4,620	3,780	4,167	247,936	2·20	2·00

* Estimate.

Missouri River at Craig, Montana.

[Drainage area, 17,615 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	....	....	*3,000	184,500	·20	·17
February	....	....	*3,000	166,500	·18	·17
March	....	....	*3,000	184,500	·20	·17
April 17 to 30	6,100	3,595	4,662	277,389	·29	·26
May	12,500	6,900	10,472	644,030	·68	·59
June	11,900	8,100	10,074	599,401	·64	·57
July	7,800	2,614	5,020	308,730	·33	·28
August	2,505	1,960	2,216	136,284	·15	·13
September	2,396	1,960	2,232	132,700	·14	·13
October	2,722	1,742	2,379	146,000	·16	·13
November	3,159	2,723	2,868	170,800	·18	·16
December	3,159	1,742	2,763	170,000	·18	·16
1891.						
January	3,823	1,742	2,967	184,270	·19	·17
February	....	....	*3,500	215,250	·24	·20
March	....	....	*4,000	246,000	·26	·23
April	9,130	4,570	5,794	344,743	·37	·32
May	12,050	7,150	9,015	554,422	·59	·51
June	16,355	11,000	13,645	811,877	·85	·77

* Estimate.

Sun River above Augusta, Montana.

[Drainage area, 1,175 square miles.]

1889.						
August 5 to 31	221	200	213	13,100	·21	·18
September	260	200	214	12,720	·20	·18
October	200	200	200	12,300	·20	·17
November	200	180	191	11,360	·18	·16
December	....	....	*175	10,760	·17	·15
1890.						
January	....	....	*175	10,760	·17	·15
February	....	....	*175	9,712	·15	·15
March	....	....	*175	10,760	·17	·15
April	1,580	160	371	22,050	·35	·31
May	4,085	1,990	2,804	172,500	2·75	2·38
June	4,000	1,850	2,342	139,500	2·23	1·99
July	2,440	450	961	59,100	·94	·81
August	480	315	371	22,800	·36	·19
September	365	260	304	18,090	·29	·26
October	480	240	315	19,395	·31	·27
November	390	275	322	19,160	·31	·28
December	340	240	267	16,430	·26	·23

* Estimate.

Yellowstone River at Horr, Montana.

[Drainage area, 2,700 square miles.]

1889.						
August 12 to 31	1,853	1,411	1,660	102,090	·71	·62
September	1,653	1,126	1,270	75,570	·52	·47
October	1,126	841	976	60,000	·42	·36
November	841	651	743	44,200	·31	·27
December	....	....	*650	39,975	·28	·24
1890.						
January	....	....	*550	33,825	·23	·25
February	....	....	*550	30,525	·21	·25
March 21 to 31	620	560	585	35,977	·25	·22
April	4,495	510	1,417	84,250	·59	·53
May	11,915	5,090	7,522	466,500	3·24	2·79
June	11,915	8,720	10,082	603,000	4·19	3·74
July	9,410	5,760	7,682	473,000	3·28	2·84
August	5,600	3,145	4,375	269,000	1·87	1·62
September	3,145	1,670	2,276	135,200	·94	·84
October	1,920	1 160	1,473	90,600	·63	·55
November	1,160	850	970	57,750	·40	·36
December	815	590	95	42,742	·30	·26
1891.						
January	590	470	488	30,012	·21	·18
February 1 to 14	....	....	*500	27,750	·19	·18
March	360	285	316	19,434	·13	·12
April	2,720	360	1,082	64,379	·45	·40
May	7,480	1,855	5,227	321,460	2·24	1·93
June	8,975	6,685	7,592	451,724	3·13	2·81

* Estimate.

Cache la Poudre Creek above Fort Collins, Colorado.

[Drainage area, 1,060 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1884.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
March 15 to 31	92	48	67	4, 120	·07	·06
April	707	64	219	13, 030	·23	·21
May	4, 610	453	2, 537	156, 025	2·77	2·39
June	5, 611	3, 473	4, 812	286, 314	5·08	4·54
July	3, 970	862	2, 144	131, 856	2·33	2·03
August	1. 231	423	792	48, 708	·86	·75
September	446	230	305	18, 147	·32	·29
October 1 to 16	224	195	205	12, 607	·22	·19
1885.						
April 4 to 30	822	241	447	26, 596	·47	·42
May	1, 592	954	1, 419	87, 268	1·55	1·34
June	3, 857	2, 235	2, 910	173, 145	3·07	2·75
July	3, 186	1, 076	3, 186	195, 939	3·46	3·01
August	1, 116	369	656	40, 344	·71	·62
September	386	214	272	16, 184	·29	·25
October 1 to 10	210	202	203	12, 484	·22	·19
1886.						
April 27 to 30	446	369	405	24, 097	·43	·38
May	2, 659	404	1, 309	80, 403	1·42	1·23
June	2, 584	1, 247	1, 876	111, 622	1·97	1·77
July	1, 175	392	717	44, 095	.78	·68
August	1, 475	232	338	20, 787	·37	·33
September	284	115	185	11, 007	·19	·17
October	133	120	129	7, 933	·14	·12
1887.						
May 18 to 29	2, 380	1, 150	1, 822	112, 053	1·99	1·72
June 14 to 30	1, 970	1, 050	1, 401	83, 360	1·47	1·32
July	1, 260	410	735	45, 202	·80	·69
August	430	240	307	18, 880	·33	·29
September	300	110	175	10, 412	·18	·17
1888.						
April	350	100	181	10, 769	·19	·17
May	790	250	483	29, 704	·53	·46
June	1, 490	680	1, 113	66, 223	1·17	1·05
July	690	260	420	25, 830	·46	·40
August	500	140	213	13, 100	·23	·20
September	180	70	109	6, 485	·11	·10
1889.						
January	342	71	151	9, 280	·16	·14
February	198	69	106	5, 880	·10	·10
March	125	41	46	2 830	·05	·04
April	342	48	113	6, 730	·12	·11
May	1, 886	215	649	39, 900	·71	·61
June	1, 960	837	1, 338	79, 500	1·41	1·26
July	844	271	514	31, 600	.56	·48
August	455	67	187	11, 500	·20	·18
September	75	56	67	3, 990	·07	·06
October	92	55	69	4, 240	·08	·06
November	122	46	88	5, 240	·09	·08
December	89	33	64	3, 940	·07	·06
1890.						
January	101	46	82	5, 043	·09	·08
February	138	37	79	4, 384	·08	·08
March	126	47	85	5, 227	·09	·08
April	481	71	200	11, 900	·21	·19
May	1, 710	436	1, 044	64, 206	1·13	·99
June	1, 804	1, 016	1, 280	76, 158	1·35	1·21
July	1, 025	336	649	39, 950	·71	·61
August	404	150	287	17, 650	·31	·27
September	183	58	103	6, 130	·11	·10
October	118	55	80	4, 925	·09	·08
November	89	41	61	3, 630	·07	·06
December	....	....	70	4, 305	·08	·07
1891.						
January	150	49	95	5, 842	·10	·09
February	138	55	75	4, 162	·07	·07
March	73	42	61	3, 751	·07	·06
April	416	48	154	9, 163	·16	·14
May	2, 080	416	1, 162	71, 463	1·26	1·10
June	....	....	....	....	....	....

Arkansas River at Canyon City, Colorado.

[Drainage area, 3,060 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1888.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	....	....	*400	24,600	·15	·13
February	....	....	*500	27,750	·17	·16
March	....	....	*600	36,900	·22	·20
April	....	....	*1,000	59,500	·36	·33
May	1,570	1,280	1,440	88,500	·54	·47
June	2,760	1,120	2,090	124,300	·76	·68
July	1,870	850	1,350	83,000	·51	·44
August	1,100	800	932	57,300	·35	·30
September	850	430	605	36,000	·22	·20
October	....	....	*500	30,750	·19	·16
November	....	....	*500	29,750	·18	·16
December	....	....	*400	24,600	·15	·13
1889.						
January	....	....	*300	18,450	·11	·10
February	....	....	*300	16,620	·10	·10
March	....	....	*300	18,450	·11	·10
April 17 to 31	438	214	300	17,850	·11	·10
May	1,960	324	600	36,900	·23	·20
June	2,010	1,002	1,374	81,753	·50	·45
July	1,150	290	602	37,023	·23	·20
August	2,620	243	340	20,910	·13	·11
September	258	190	220	13,090	·08	·07
October	284	190	223	13,715	·08	·07
November	335	243	299	17,790	·11	·10
December	438	274	335	20,602	·13	·11
1890.						
January	494	180	310	19,065	·12	·10
February	446	250	363	20,146	·12	·12
March	391	180	320	19,683	·12	·10
April	980	200	477	28,381	·17	·16
May	3,270	841	2,090	128,535	·79	·68
June	3,260	2,068	2,611	155,354	·95	·85
July	2,132	920	1,571	96,616	·59	·51
August	1,425	580	670	41,205	·25	·22
September	625	455	519	30,850	·19	·17
October	605	505	531	32,650	·20	·17
November	555	480	522	31,060	·19	·17
December	580	455	502	30,900	·19	·16
1891.						
January	505	325	431	26,506	·16	·14
February	580	365	474	26,307	·16	·15
March	685	530	586	36,039	·22	·19
April	1,600	580	857	50,992	·31	·28
May	3,370	1,340	2,012	123,738	·76	·66
June	4,230	1,600	3,291	195,814	1·20	1·07

Rio Grande at Del Norte, Colorado.

[Drainage area, 1,400 square miles.]

1889.						
October 11 to 31	345	214	278	17,097	·23	·20
November	364	290	319	18,980	·25	·23
December	364	200	281	17,281	·23	·20
1890.						
January	1,000	326	552	33,948	·45	·39
February	896	745	796	44,178	·59	·57
March	842	404	487	29,950	·40	·35
April	1,380	404	913	54,323	·73	·65
May	5,930	1,990	4,331	266,356	3·57	3·09
June	5,555	2,550	3,807	226,516	3·03	2·72
July	2,260	862	1,515	93,172	1·25	1·08
August	930	450	612	37,638	·50	·44
September	450	326	383	22,800	·31	·27
October	862	307	470	28,900	·39	·34
November	610	345	478	28,500	·38	·34
December	670	475	565	34,750	·46	·40
1891.						
January	1,320	670	990	60,885	·81	·71
February	1,410	1,193	1,294	71,817	·96	·92
March	1,460	930	1,280	78,720	1·05	·91
April	3,160	796	1,410	83,895	1·12	1·01
May	5,650	1,860	3,285	202,027	2·70	2·34
June	5,555	2,190	4,146	246,687	3·31	2·96

Rio Grande at Embudo, New Mexico.

[Drainage area, 7,000 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	495	379	431	26, 506	·07	·06
February	576	420	473	26, 251	·07	·07
March	1, 042	537	784	48, 216	·13	·11
April	4, 420	970	2, 261	134, 530	·36	·32
May	5, 075	2, 443	3, 430	210, 945	·56	·49
June	5, 660	1, 390	2, 922	173, 859	·47	·42
July	1, 105	236	471	28, 966	·07	·07
August	253	181	206	12, 669	·03	·03
September	264	184	212	12, 614	·03	·03
October	324	243	283	17, 404	·05	·04
November	507	253	366	21, 777	·06	·05
December	610	364	542	33, 333	·09	·08
1890.						
January	617	260	437	26, 875	·07	·07
February	670	344	553	30, 691	·08	·08
March	1, 044	330	682	41, 943	·11	·10
April	3, 220	842	2, 083	123, 938	·33	·30
May	6, 071	2, 660	4, 960	305, 040	·82	·71
June	5, 740	2, 768	4, 107	244, 366	·65	·59
July	2, 640	920	1, 593	97, 969	·26	·23
August	1, 134	636	814	50, 061	·13	·12
September	1, 044	496	545	32, 400	·09	·08
October	606	523	562	34, 600	·09	·08
November	699	550	616	36, 650	·10	·09
December	660	636	648	39, 850	·11	·09
1891.						
January	666	550	586	36, 039	·10	·08
February	1, 000	550	616	34, 182	·09	·09
March	1, 450	735	917	56, 395	·16	·13
April	5, 690	735	2, 370	141, 015	·38	·34
May	8, 550	4, 520	5, 965	366, 847	·98	·85
June	6, 340	4, 325	5, 040	299, 880	·80	·72

Rio Grande at El Paso, Texas.

[Drainage area, 30,000 square miles].

1889.						
May 10 to 31	4, 705	2, 060	3, 116	191, 634	·120	·104
June	4, 460	660	2, 638	156, 961	·098	·090
July	930	....	237	14. 575	·009	·007
August	....	....	0	0	0	0
September	....	....	0	0	0	0
October	....	....	0	0	0	0
November	....	....	0	0	0	0
December	252	....	71	4, 366	·003	·002
1890.						
January	280	126	196	12, 054	·008	·007
February	458	108	290	16, 095	·010	·010
March	1, 140	45	424	26, 076	·016	·014
April	4, 108	470	2, 190	130, 305	·081	·073
May	7, 200	3, 495	5, 771	354, 916	·221	·190
June	7, 200	2, 925	4, 404	262, 038	·164	·147
July	2, 355	235	854	52, 521	·033	·028
August	2, 497	170	734	45, 141	·028	·024
September	660	40	176	10, 470	·006	·006
October	616	40	65	4, 000	·003	·002
November	610	40	284	16, 950	·011	·009
December	610	430	535	32, 900	·020	·018
1891.						
January	715	140	451	27, 736	·017	·015
February	2, 640	470	809	44, 899	·028	·027
March	4, 635	470	1, 866	114, 759	·072	·062
April	8, 625	1, 040	4, 265	253, 767	·159	·142
May	16, 620	8, 340	11, 852	726, 528	·454	·396
June	8, 340	5, 045	6, 714	399, 483	·249	·224

Truckee River at Vista, Nevada.

[Drainage area, 1,519 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
April 26 to 30	5,610	3,730	4,496	267,512	3·30	2·96
May	7,510	3,200	5,990	368,385	4·55	3·94
June	6,710	3,115	4,162	247,639	3·06	2·74
July	3,730	1,185	2,198	135,177	1·67	1·45
August	1,152	750	952	58,548	·72	·63
September	825	570	682	40,579	·50	·45
October	1,030	490	742	45.633	·56	·49
November	825	400	765	45,517	·56	·50
December	....	....	*750	46,125	·57	·49
1891.						
January	....	....	*700	43,050	·54	·46
February	....	....	*650	36,075	·44	·43
March	....	....	*650	39,975	·50	·43
April	3,115	570	1,523	90,618	1·12	1·00
May	3,285	1,990	2,765	170,047	2·10	1·79
June	2,730	1,280	1,905	113,347	1·39	1·25

* Estimate.

East Carson River at Rodenbahs, Nevada.

[Drainage area, 414 square miles.]

1890.						
April 7 to 30	1,565	752	1,026	61,047	2·76	2·48
May 4 to 31	4,260	1,315	2,654	163,221	7·38	6·41
June	3,900	1,745	2,430	144,585	6·55	5·87
July	2,780	750	1,789	110,000	4·98	4·32
August	875	437	597	36,750	1·66	1·44
September	437	400	415	24,700	1·12	1·00
October	390	385	386	23,740	1·07	·93
November	385	380	384	22,850	1·04	·93
December	400	375	379	23,300	1·06	·92
1891.						
January	395	385	388	23,862	1·08	·94
February	715	377	402	22,311	1·01	·97
March	1,650	390	783	48,154	2·18	1·89
April	590	410	452	26,894	1·22	1·09
May	1,884	1,010	1,445	88,867	4·02	3·49
June	1,884	565	1,328	79,016	3·58	3·12

West Carson River at Woodford, California.

[Drainage area, 70 square miles.]

1890.						
April 9 to 30	448	145	284	16,898	4·56	4·06
May	924	318	657	40,405	10·83	9·40
June	1,284	448	614	36,533	9·79	8·77
July	606	252	380	23,370	6·27	5·43
August	240	90	135	8,300	2·23	1·93
September	86	70	75	4,080	1·09	1·07
October	78	54	67	4,120	1·10	·96
November	58	46	49	2,915	·78	·70
December	58	42	53	3,261	·87	·76
1891.						
January	62	46	52	3,198	·86	·74
February	58	42	48	2,664	·71	·69
March	68	50	61	3,758	1·01	·87
April	384	62	127	7,556	2·02	1·82
May	740	300	534	32,820	8·79	7·62
June	456	260	338	20,111	5·38	4·83

Bear River at Battle Creek, Idaho.

[Drainage area, 4,500 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
October 11 to 31	430	300	355	21, 832	·09	·07
November	830	430	487	28, 976	·12	·11
December	735	350	565	34, 747	·14	·13
1890.						
January	1, 255	270	875	53, 812	·22	·19
February	2, 040	600	809	4, 490	·18	·18
March	2, 040	780	1, 271	78, 166	·32	·28
April	3, 960	2, 170	2, 978	177, 191	·74	·66
May	5, 980	3, 960	5, 199	319, 738	1·33	1·60
June	5, 980	2, 300	4, 074	245, 000	1·02	·91
July	2, 170	1, 200	1, 582	97, 293	·40	·35
August	1, 200	880	1, 000	61, 500	·26	·22
September	880	780	843	50, 150	·21	·19
October	880	780	854	52, 500	·22	·19
November	880	780	783	46, 600	·19	·17
December	780	690	748	46, 000	·19	·17
1891.						
January	690	690	690	42, 435	·18	·15
February	....	....	780	43, 290	·18	·17
March	880	780	790	48, 585	·20	·17
April	2, 950	780	1, 623	96, 509	·40	·36
May	3, 030	2, 440	2, 652	163, 098	·68	·59
June	2, 870	1, 660	2, 245	133, 578	·56	·50

Bear River at Collinston, Utah.

[Drainage area, 6,000 square miles.]

1889.						
June	....	....	*800	47, 600	·15	·13
July 24 to 31	385	340	362	22, 263	·07	·06
August	450	385	417	25, 645	·08	·07
September	610	450	509	30, 285	·09	·08
October	825	610	728	44, 772	·14	·12
November	1, 000	780	848	50, 456	·16	·14
December	1, 925	955	1, 395	85, 792	·27	·23
1890.						
January	....	....	*1, 500	92, 250	·29	·25
February	....	....	*1, 000	55, 500	·17	·17
March 2 to 31	4, 850	1, 100	3, 188	196, 062	·61	·53
April	6, 680	3, 600	4, 953	294, 703	·92	·83
May	8, 220	6, 890	7, 924	487, 326	1·52	1·32
June	7, 940	4, 440	6, 234	270, 923	1·16	1·04
July	4, 230	2, 060	3, 250	199, 875	·62	·54
August	2, 060	1, 545	1, 754	107, 871	·34	·29
September	1, 425	1, 310	1, 344	80, 050	·25	·22
October	1, 665	1, 365	1, 544	95, 000	·30	·26
November	1, 425	1, 365	1, 403	83, 500	·26	·23
December	1, 545	1, 000	1, 243	76, 500	·24	·20
1891.						
January	....	....	1, 000	61, 500	·19	·17
February	2, 200	825	1, 308	72, 594	·22	·22
March	2, 340	1, 425	1, 766	108, 710	·34	·29
April 1 to 11	5, 000	1, 665	2, 729	162, 375	·51	·45
May	5, 000	4, 020	4, 569	280, 993	·88	·76
June	4, 720	2, 480	3, 595	213, 902	·67	·60

Estimate.

Ogden River at Powder Mills, Utah.

[Drainage area, 360 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
August 9 to 31	60	40	50	3,075	·16	·14
September	70	50	52	3,094	·16	·14
October	145	70	89	5,473	·28	·24
November	253	60	105	6,247	·33	·29
December	735	145	421	25,891	1·35	1·17
1890.						
January	510	289	382	23,493	1·22	1·06
February	1,364	399	680	37,740	1·97	1·89
March	1,401	362	978	60,147	3·13	2·72
April	1,919	1,068	1,449	86,215	4·49	4·02
May	2,178	1,475	1,818	111,807	5·82	5·05
June	1,438	624	910	54,145	2·82	2·53
July	624	326	458	28,167	1·47	1·27
August	473	215	312	19,188	1·00	·86
September	235	195	206	12,260	·64	·57
October	326	215	265	16,290	·85	·74
November	267	235	255	15,180	·79	·71
December	----------	----------	*240	14,760	·77	·67

* Estimate.

Weber River in canyon above Uinta, Utah.

[Drainage area, 1,600 square miles.]

1889.						
October 13–31	290	130	181	11,131	·13	·11
November	290	160	208	12,376	·14	·12
December	815	200	430	26,445	·31	·27
1890.						
January	815	290	457	28,105	·33	·29
February	1,400	200	547	30,358	·36	·34
March	2,130	200	1,091	67,096	·79	·68
April	4,280	970	2,184	129,948	1·52	1·36
May	5,465	3,470	4,528	278,472	3·26	2·83
June	3,635	1,220	2,017	120,011	1·41	1·27
July	1,220	290	549	33,763	·40	·34
August	450	200	280	17,220	·20	·18
September	290	240	265	15,750	·18	·17
October	450	200	331	19,850	·22	·21
November	340	290	298	17,720	·21	·19
December	340	240	290	17,830	·21	·18
1891.						
January	450	290	303	18,634	·23	·19
February	1,220	290	461	25,586	·30	·29
March	1,220	450	625	38,437	·45	·39
April	2,420	520	1,502	89,369	1·05	·94
May	4,655	1,940	2,752	169,250	1·98	1·72
June	2,225	1,135	1,621	96,449	1·13	1·01

Provo River above Provo, Utah.

[Drainage area, 640 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
July 27–31	150	149	150	9,225	·27	·23
August	149	144	145	8,917	·26	·23
September	174	144	150	8,925	·26	·23
October	200	174	180	11,070	·32	·28
November	280	200	224	13,328	·39	·35
December	630	240	384	23,616	·69	·60
1890.						
January	700	200	305	18,751	·55	·48
February	564	280	377	20,923	·61	·59
March	700	240	519	31,990	·94	·81
April	1,240	500	840	49,980	1·46	1·32
May	2,180	1,316	1,926	118,450	3·47	3·01
June	2,260	440	1,184	70,448	2·06	1·85
July	440	280	314	19,311	·56	·49
August	280	240	252	15,498	·45	·39
September	280	240	244	14,520	·43	·38
October	330	280	304	18,700	·55	·48
November	330	280	303	18,020	·53	·47
December	330	240	293	18,020	·53	·46
1891.						
January	280	240	255	15,682	·46	·40
February	500	280	311	17,240	·50	·48
March	1,316	280	492	30,258	·89	·77
April	930	280	478	28,430	·83	·75
May	1,704	851	1,226	75,399	2·21	1·92
June	1,470	851	1,190	70,805	2·07	1·86

Spanish Fork in canyon, Utah.

[Drainage area, 670 square miles.]

1889.						
September	70	45	50	2,975	·08	·07
October	70	50	62	3,813	·11	·09
November	70	45	63	3,153	·09	·08
December	70	50	67	4,120	·12	·10
1890.						
January	230	50	68	4,182	·12	·10
February	95	50	76	4,218	·12	·11
March	355	50	143	8,794	·25	·21
April	770	150	387	23,026	·64	·58
May	1,040	355	777	47,785	1·34	1·15
June	355	110	205	12,197	·34	·31
July	590	82	114	7,011	·20	·17
August	82	50	64	3,837	·11	·10
September	95	50	63	3,750	·10	·09
October	95	50	64	3,938	·11	·10
November	50	50	50	2,975	·08	·07
December	50	50	50	3,075	·09	·07

Sevier River at Leamington, Utah.

[Drainage area, 5,595 square miles.]

Month.	Discharge. Max.	Discharge. Min.	Discharge. Mean.	Total for month.	Run-off. Depth.	Run-off. Per sq. m.
	Second-ft.	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
1889.						
August 23 to 31	60	40	48	2,952	·01	·008
September	80	48	53	3,153	·01	·009
October	160	48	111	6,826	·02	·019
November	444	210	274	16,303	·05	·049
December	526	280	395	24,292	·08	·071
1890.						
January	1,058	280	625	38,437	·13	·11
February	1,140	567	713	39,571	·13	·13
March	690	567	630	38,745	·13	·11
April	976	608	726	43,197	·14	·13
May	2,329	976	1,705	104,857	·35	·31
June	2,206	649	1,250	74,375	·25	·22
July	649	185	346	21,279	·07	·06
August	185	150	153	9,409	·03	·03
September	185	150	157	8,345	·03	·03
October	362	185	310	19,050	·06	·06
November	403	321	373	22,100	·07	·07
December	649	403	509	31,320	1·05	·09
1891.						
January	772	649	735	45,202	·15	·13
February	772	772	772	42,846	·14	·14
March	772	526	618	38,007	·13	·11
April	608	526	503	29,928	·10	·09
May	1,386	608	1,114	68,511	·23	·20
June	1,140	567	952	56,644	·19	·17

Henry Fork in canyon, Idaho.

[Drainage area, 931 square miles.]

1890.						
January	....	....	*1,200	738,000	1·49	1·29
February	....	....	*1,250	69,375	1·40	1·35
March	....	....	*1,300	79,950	1·61	1·40
April 6 to 30	4,920	1,120	1,875	111,562	2·25	2·01
May	7,710	2,750	4,580	281,670	5·67	4·92
June	2,890	1,860	2,270	135,065	2·72	2·44
July	1,860	1,450	1,550	95,325	1·92	1·66
August	1,450	1,450	1,450	89,175	1·80	1·56
September	1,450	1,280	1,314	78,183	1·57	1·41
October	1,280	1,280	1,280	78,720	1·59	1·38
November	1,280	1,280	1,280	76,150	1·55	1·37
December	1,280	1,280	1,280	78,720	1·59	1·38
1891.						
January	1,280	1,280	1,280	78,720	1·59	1·38
February	1,280	1,280	1,280	71,040	1·43	1·38
March	1,280	1,280	1,280	78,720	1·59	1·38
April	2,600	1,280	1,516	90,505	1·83	1·63
May	3,180	1,640	2,184	134,316	2·71	2·33
June	2,215	1,450	1,801	107,160	2·16	1·94

* Estimate.

Falls River in canyon, Idaho.

[Drainage area, 594 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
April 25 to 30	2,480	1,250	1,730	102,935	3·25	2·92
May	4,440	2,630	3,342	205,533	6·49	5·63
June	4,050	2,030	2,706	161,007	5·08	4·56
July	2,630	1,030	1,669	102,643	3·20	2·81
August	1,140	840	971	59,717	1·82	1·63
September	930	660	774	46,000	1·45	1·30
October	750	570	660	39,950	1·26	1·09
November	570	480	541	30,360	·95	·86
December	480	480	520	29,520	·93	·81
1891.						
January	590	450	509	31,304	·99	·86
February			*450	24,975	·79	·76
March			*450	27,675	·87	·76
April	1,140	450	606	36,057	1·14	1·02
May	2,790	1,030	1,765	108,547	3·43	2·98
June	2,180	1,370	1,681	100,019	3·17	2·85

* Estimate.

Teton River at Chase's ranch, Idaho.

[Drainage area, 967 square miles.]

1890.						
April 5 to 30	1,295	545	740	44,030	·85	·77
May	4,445	1,545	2,730	167,895	3·26	2·82
June	4,065	1,925	2,812	167,314	3·26	2·91
July	2,950	935	2,130	130,995	2·54	2·20
August	935	510	678	41,700	·81	·70
September	510	450	462	27,500	·53	·48
October	510	450	475	29,200	·57	·49
November	450	450	450	26,700	·52	·46
December	510	450	459	28,200	·55	·47
1891.						
January			*400	24,600	·48	·41
February 17 to 28	475	450	465	22,807	·56	·47
March	450	450	450	27,675	·54	·47
April	935	450	630	37,485	·72	·65
May	2,360	720	1,402	86,223	1·66	1·45
June	2,360	1,295	1,661	98,829	1·91	1·72

* Estimate.

Snake River at Eagle Rock or Idaho Falls, Idaho.

[Drainage area, 10,100 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
July	8,646	3,174	5,184	318,816	·59	·51
August	3,130	2,286	2,594	159,654	·30	·26
September	2,508	2,286	2,300	136,850	·25	·23
October	2,730	2,286	2,425	149,137	·28	·24
November	2,952	2,508	2,737	162,851	·30	·27
December	2,730	2,508	2,601	159,961	·30	·26
1890.						
January	....	....	*2,000	123,000	·23	·20
February	....	....	*2,000	111,000	·21	·20
March	....	....	*2,000	123,000	·23	·20
April	15,000	2,900	5,702	339,269	·63	·57
May	49,350	16,900	35,606	2,189,769	4·06	3·52
June	50,450	24,930	34,870	2,074,765	3·85	3·45
July	28,800	10,700	19,970	1,228,155	2·28	1·98
August	10,350	6,250	7,875	484,312	·90	·79
September	5,950	4,350	4,934	293,800	·54	·48
October	4,600	4,350	4,552	280,000	·52	·45
November	4,350	3,900	4,207	250,000	·47	·42
December	....	....	*3,900	239,850	·45	·39

* Estimate.

Owyhee River at Rigsbys, Oregon.

[Drainage area, 9,875 square miles.]

1890.						
March 26 to 31	7,350	5,190	6,140	377,610	·72	·62
April	8,225	5,395	6,558	390,201	·74	·66
May	11,230	3,010	5,913	363,649	·69	·60
June	2,850	620	1,403	83,478	·16	·14
July	560	200	343	21,094	·04	·03
August	200	170	179	11,108	·02	·02
September	170	170	170	10,115	·02	·02
October	170	170	170	10,455	·02	·02
November	280	221	221	13,150	·02	·02
December	360	280	309	19,004	·04	·03
1891.						
January	400	360	320	22,140	·04	·04
February	3,265	450	932	51,726	·10	·09
March	4,335	2,600	3,313	203,649	·39	·34
April	10,000	2,900	4,984	296,548	·56	·51
May	4,600	2,075	3,114	191,511	·36	·31
June	2,150	500	1,267	75,386	·14	·13

Malheur River at Vale, Oregon.

[Drainage area, 9,900 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
March 20 to 31	4,445	1,840	2,912	179,088	·34	·29
April	3,450	2,180	2,770	164,815	·31	·28
May	2,890	590	1,627	100,060	.19	·16
June	520	120	254	15,113	·03	·02
July	90	25	43	2,644	·005	·004
August	25	15	17	1,011	·002	·002
September	15	15	15	893	·002	·001
October	62	15	44	2,705	·005	·004
November	150	70	118	7,010	·013	·012
December	115	62	83	5,105	·009	·008
1891.						
January	115	70	88	5,412	·01	·009
February	2,820	80	319	17,704	·03	·03
March	1,460	260	703	43,234	·08	·07
April	665	325	511	30,404	·06	·05
May	325	115	217	13,345	·03	·02
June	185	45	78	4,641	·01	·01

Weiser River in canyon, Idaho.

[Drainage area, 1,670 square miles.]

1890.						
March 13 to 31	11,220	1,550	5,773	355,039	3·99	3·45
April	7,060	2,470	4,792	285,124	3·20	2·87
May	7,060	2,610	4,882	300,243	3·37	2·92
June	2,470	1,280	1,792	106,624	1·20	1·07
July	1,130	220	590	36,285	·41	·35
August	190	100	138	8,487	·09	·08
September	140	80	103	6,135	·07	·0[illegible]
October	190	140	166	10,200	·11	·10
November	400	160	222	13,200	·15	.13
December	480	280	396	24,350	·28	·24
1891.						
January	320	190	292	17,958	·20	·17
February	1,860	320	678	37,629	·42	·41
March	9,300	1,010	2,855	175,582	1·97	1·71
April	2,220	1,260	1,777	105,731	1·26	1·06
May	1,640	1,010	1,331	81,856	·93	·80
June	1,010	500	703	41,828	·47	·42

MONTHLY PERCENTAGES OF RUN-OFF.

The following table, giving the relative discharges of various streams during each month of the year, has been prepared for the purpose of aiding in approximations of discharge when but one or two measurements are available. The table shows the percentage of the average discharge for one month to the total for the year, and from these figures, based on actual measurements, certain inferences may be drawn. The years have been arbitrarily selected, the period being governed largely by the time at which gaugings were begun, and during which they were carried on. For example, in the first instance in the year from August 1, 1889, to July 31, 1890, the discharge during June was 27·4 per cent of the total discharge of the year, but taking the time from January 1, 1890, to December 31, 1890, the discharge for

3·6	4·1	6·7	21·7	38·2	11·8	2·6	2·2	1·7	1·9	1·7	3·8
4·8	5·9	8·1	13·1	30·2	18·5	2·4	2·3	2·4	2·8	3·5	6·0
4·4	5·5	7·6	12·2	28·1	17·3	4·6	3·7	3·5	4·4	4·4	4·3
4·5	5·5	8·7	8·5	21·6	21·0	5·5	4·4	4·3	5·4	5·4	5·2
3·3	3·7	6·9	18·8	37·6	9·9	5·5	3·1	2·4	3·0	2·6	3·2
3·3	3·7	6·9	18·9	37·7	9·9	5·5	3·1	3·1	3·1	2·4	2·4
9·1	10·4	9·2	10·5	24·8	18·2	5·0	0·7	0·8	1·6	4·0	5·7
8·3	9·5	8·4	9·7	22·8	16·7	4·6	2·0	2·1	4·1	5·0	6·8
11·2	11·8	9·5	7·7	17·1	14·5	5·3	2·3	2·4	4·7	5·7	7·8
5·8	6·1	6·3	9·1	22·2	11·0	7·5	7·0	6·4	6·2	6·2	6·2
7·3	7·3	7·3	8·7	12·5	10·3	8·9	8·3	7·5	7·3	7·3	7·3
3·6	3·1	3·1	12·1	23·4	18·9	11·6	6·8	5·4	4·6	3·8	3·6
3·3	3·8	3·7	6·0	22·3	22·9	17·4	5·5	3·8	3·9	3·7	3·7
2·0	2·0	2·0	5·7	35·6	34·9	5·2	2·6	2·3	2·4	2·7	2·6
1·6	1·6	1·6	4·5	28·0	27·3	15·5	6·2	3·9	3·5	3·2	3·1
1·8	4·7	16·7	33·0	29·7	7·1	1·7	0·9	0·9	0·9	1·1	1·5
[illegible]·0	4·8	34·8	33·1	19·5	3·0	0·5	0·2	0·2	0·5	1·4	1·0
[illegible]5	3·4	29·1	24·2	24·6	9·1	3·0	0·7	0·5	0·8	1·1	2·0